DESIGNER AND CONSTRUCTOR PRACTICES TO ENSURE LIFE CYCLE PERFORMANCE

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1 INTRODUCTION

Technology advances of the last few decades, in such areas as computing and construction materials, have inspired many attempts to improve the construction process. Many of these attempts focus on reducing costs and improving functionality, such as life cycle cost analysis and value engineering, while others, such as design-build, focus on specific phases of the life cycle. Other factors such as declining productivity, the quantity of construction and demolition waste produced, rising construction costs and the current phase of redevelopment and reconstruction for much of the nation's infrastructure also motivate scrutiny of life cycle planning practices.

Each phase of a facility's life cycle places requirements on the features of the facility that may be thought of as properties of the facility. While much emphasis has been placed upon constructability, relatively little attention has been given to parallel aspects of other phases of the facility life cycle. Designability, maintainability, operability, reconstructability and deconstructability practices should all be considered in an approach to optimize the overall value of a facility. The total value or performance of a facility is embodied in how fully each of these properties is developed versus the effort (cost) in developing them. It is apparent that a mechanism needs to be developed to look at the technical aspects of the entire life cycle of the facility, not strictly as a function of lowest cost for a limited number of phases, but as a function of total value.

This report documents one portion of a joint research effort between the University of Washington Department of Civil Engineering and the University of Nevada at Las Vegas Department of Civil Engineering addressing industry practices regarding the life-cycle properties in constructed facilities. The first major goal of this research effort is to establish a better understanding of the life-cycle properties that are currently being addressed and what formal processes are in place to monitor how effectively these properties are being addressed.

This particular report summarizes the results of a questionnaire mailed to constructors and designers in Washington State. Further research will be conducted on the opinions and practices of owners and construction mangers in Washington State and all four parties in the California/Nevada region.

CHAPTER 2 BACKGROUND

2.1 Life Cycle Concepts

Some of the methods that have been developed and promoted to enhance the value of constructed facilities include life cycle cost analysis, value analysis and value engineering. Design-build and commissioning are two of the more recent developments being used to improve the planning and life cycle needs of the facility. The following sections provide an overview of these concepts and thus a backdrop for the life cycle property framework.

2.1.1 Life Cycle Cost Analysis

Taken from engineering economics, life cycle cost analysis is a tool used to assist in making decisions when faced with more than one option (Bull 1993). Life cycle costing attempts to identify all costs related to the facility, including research and development, construction costs, operation and maintenance costs, and demolition or salvage costs (Seldon 1979). For a detailed treatment of life cycle costing methodology, the reader is referred to *Life Cycle Cost Data* by Dell'Isola and Kirk (1983). Usually there will be two or more proposals that are under consideration. The life cycle costs are estimated for each alternative. A decision on the proposal with which to proceed is made based on either total life cycle costs or initial costs. While it would be ideal to base the selection decision on complete life cycle cost estimates, the traditional scarcity of complete cost records beyond the construction phase often results in an unacceptable degree of uncertainty in such cost projections (Bull 1993). Life cycle costing does attempt to include all definable life cycle costs, but it does not incorporate decisions based on the technical merits of the alternatives.

2.1.2 Value Analysis and Value Engineering

Value analysis, born in the late 1940's, looks at facilities (or projects), attempts to identify any problems and makes recommendations on problem solving solutions (Fowler 1990). This system is generally used to look at the functions associated with a facility and develop alternate, less expensive solutions. Because the aim of value analysis, as it is currently used, is to provide the required functions at the lowest cost, the incentive, again is to use lowest cost, but functional items (Fowler 1990). Because there is an attempt to maintain functionality, value analysis does address the operational properties (operability) of the facility and perhaps the maintenance properties. The bottom line emphasis on costs in one or two isolated life cycle phases, however, may increase costs in a subsequent phase.

Similar to value analysis, value engineering is a spin-off of value analysis that is more common in the construction industry. Like value analysis, value engineering looks at the least expensive solution to meet functional requirements (Brown 1992). Value engineering is a process of functional analysis that provides the least expensive solution to meet the functional requirements (Palmer et al. 1996). Because value engineering is based on least expensive items, this does not allow for more appropriate long-term technical items to be included. The United States Government includes value engineering clauses in all of its construction contracts. Contractors then submit value engineering change proposals, which may result in the contractor and the government sharing in the cost savings (Dell'Isola 1982). In the private sector, a team of outsiders generally performs value engineering, with the project engineer excluded. This leads to some degree of second-guessing the design decisions that have been made (Fowler 1990). Both value analysis and value engineering are performed during the design phase, which limits its usefulness throughout the entire life cycle of the facility.

2.1.3 Design-Build

Design-build is a contractual mechanism that encourages early discussion between the designer and the constructor. Because the constructor is involved during the early stages, duplicate and redundant efforts in the design process can be eliminated (Fredrickson 1998). In many cases, the design-build process does improve the design and construction phases, but still does not take into consideration the remaining phases of a facility's life-cycle.

2.1.4 Commissioning

Commissioning started out as the testing and balancing of completed building systems; it has been expanding in recent years to include all aspects related to a project's complete development (Post 1998). This whole-building commissioning uses an agent, acting on behalf of the owner, to monitor and provide oversight through design development and construction, and into startup, operations and maintenance of the facility. Retro-commissioning describes a similar service that begins during the operations and maintenance phase. Advocates maintain that because the agent is involved in the operations and maintenance of the facility, more input can be provided during the design phase to reduce later costs (Post 1998). Only a few guidelines exist for this type of commissioning and the advantages have yet to be quantified. Finally, although commissioning is more involved in the life cycle of the facility, it still does not generally take into consideration reconstruction or deconstruction.

2.1.5 Summation

Several concepts have been developed and are utilized to examine costs and functional features associated with constructed facilities. However, none of these procedures are aimed at considering the complete "cradle-to-grave" picture of the

facility. The most recently developed concept of commissioning comes closest to fulfilling this need, but does not include conversion or demolition of the facility.

Dependable cost estimates for later project life cycle phases (operations, maintenance, etc.) are still a thing of the future, but are becoming more of a real possibility as computer databases are facilitating the tracking of these costs. Until better records become available, there is still a need to examine the facility life cycle in terms of its technical features. Once functional requirements are met, cost alternatives may be examined accordingly, as data becomes available.

2.2 Life Cycle Properties

As shown in the previous sections, the literature indicates that there is no current mechanism in place that formally addresses all of the life cycle properties of a facility, from design to deconstruction. The object of this study is to determine which properties are being addressed by the different groups involved in the life of a facility, as well as to determine the degree of importance of these properties and the measures being used to measure the success of addressing these properties. A brief discussion and working definition used in this study for each of these properties is presented below.

The life cycle of a facility can be broken into six defined segments: design, construction, operations and maintenance, reconstruction and deconstruction. Describing performance in terms of properties that correspond to these life cycle phases provides a framework for assessing total quality of a facility.

Table 2.1 shows the various functions associated with a facility's life cycle, as well as the life cycle property associated with that function and the relative cost of the various functions and properties. Facility management (operability and maintainability) typically accounts for up to 80% of the total costs of a facility.

While construction costs are also relatively higher than renovation and deconstruction, design costs are the lowest, as little as 25% of the total cost of the facility (Bull 1993). Because it is easiest to identify the design and construction costs, these are most often reduced to cut initial costs, with little or no consideration given to the operations and maintenance phases of the life cycle.

Table 2.1 Life Cycle Functions and Properties

Function	Property	Relative Cost
Design (Creation)	Designability	$
Construction (Fabrication)	Constructability	$$$
Facility Management (Operation/Maintenance)	Operability Maintainability	$$$$
Addition/Demolition (Re/Deconstruction)	Reconstructability Deconstructability	$$

2.2.1 Designability

Designability is the property that reflects the ease of designing and engineering a proposed project scope. The level of designability is influenced by factors that inhibit or promote the design effort. Examples are sight conditions, owner requirements, environmental constraints, time and budget for design, etc. The worst case scenario results in abandonment of the project while the best case yields a complete design within time and budget.

2.2.2 Constructability

Constructability is the property that reflects the ease of construction of a project's design and the clarity and completeness of a project's contract documents. Choices of building systems, materials and general complexity of the design are

examples of parameters that impact this property. This property is typically the most studied of the various life cycle properties. Kartam (1996), discusses specific benefits of using lessons learned to improve constructability, while Hanlon and Sanvido (1995) provide another method of integrating constructability information into a project's design.

2.2.3 Maintainability

Maintainability is the property that reflects the reliability and ease of servicing, repair and replacement of any active and passive systems in a facility. Major issues related to this property are required frequency and nature of repairs, and access to systems requiring maintenance and repair (Clayton et al. 1990, Blanchard et al. 1995). The relatively long duration of the O&M phase of the life cycle may result in an extremely high total cost for high maintenance facilities. The cost includes not only repairs, but also inconvenience to occupants and users.

A specific example of this is discussed by Rosenbaum (1997), where a warehouse floor was constructed with one-tenth as many control joints in order to reduce future maintenance. Alexander (1974) discusses maintainability and expected cost decision analysis, in relation to highway design, as a tool to be used in making decisions regarding the initial costs and future costs. Maintainability, as presented by Moncarz et al. (1986), is interpreted as a choice between no maintenance and low maintenance passive or active systems. One element of maintainability, review during the constructability reviews is discussed in depth by Williamson's (1996) with respect to the building envelope.

2.2.4 Operability

Operability is the property that reflects the accessibility, functionality, and ease of manipulation and control of all operable systems in a facility. This property describes how well the facility and its systems meet the requirements of the owner, occupants or other users. Issues of lighting levels, environmental controls, space, access, conveyance systems, etc. are associated with operability (Clayton et al. 1990).

2.2.5 Reconstructability

Reconstructability is the property that reflects the ease of modifying or augmenting a facility to meet a future alternative or expanded functional requirement. An important factor for this property is the quality of as-built drawings. This property is more relevant for owners of large campuses where facilities are likely to the converted for alternative uses or for transportation facilities that may require significant upgrades to meet increased demands. It is recognized that this property may not be of concern to many other owners.

2.2.6 Deconstructability

Deconstructability is the property that reflects the ease of dismantling and removing a facility or system in a facility so that the facility no longer meets its originally intended purpose. Planning for nuclear facility decommissioning is the best example of this property (Abraham and Merkel 1997). Another issue associated with deconstructability is the salvageability of a facility's subsystems and the contribution to the C&D waste stream.

CHAPTER 3 SURVEY INSTRUMENT AND RESULTS

3.1 Description of Survey

The survey consisted of three sections. The first section contained questions dealing with the personal characteristics of the respondent and the company that the respondent was representing. The second section dealt with the proprieties that were formally addressed by the respondent's firm. This section also asked for a relative ranking of the properties addressed, the practices by which the life cycle properties are formally addressed, the stage of a project in which these properties are addressed, and the measures used to determine the effectiveness of addressing the life cycle properties. The third section of the survey asked the respondents to rank the six properties in terms of importance in achieving maximum value in the constructed facility. This section also asked the respondent to identify which parties were responsible for addressing each of the life cycle properties. Copies of the versions of the survey that were sent to constructors and designers are in Appendix A.

For this phase of the research project, the survey was sent to 272 constructors and 156 designers. The recipients were members of the Association of Building Contractors (ABC), the Association of General Contractors (AGC), or the Consulting Engineers Council of Washington (CECW). All of the recipients were located in Washington State. During the next phase of this project, surveys will be sent to construction managers and owners, in the Pacific Northwest, as well as to representatives of all four parties in the Nevada/California region.

A summary of the data is available in Appendix B

3.2 Population Characteristics

Of the 272 constructor surveys sent out, 16 were completed and 4 were returned because the respondents felt they did not have the proper knowledge to complete the survey. Of the 156 designer surveys sent, 25 were returned as completed, with an additional 4 returned due to lack of experience or knowledge. The response rate was 7% and 19% for constructors and designers, respectively. This low response rate is most likely due to the fact that owners and construction managers are more likely to be concerned with the entire life of the project, while constructors and designers are focused on the initial stages of the facilities' life-cycle. Because this survey focuses on the entire facility life, this may have caused many to feel that they did not have a vested interest in the results, therefore not returning the survey. On specific questions, survey responses were discarded from the analysis when the response was deemed incorrect or incomplete. The practice usually eliminated one or two responses from the analysis for any one question.

3.2.1 Constructor Profiles

The majority of the constructor respondents were presidents or CEO's, with an average of 26 years of experience in the construction industry and 25 years as a constructor. The average annual revenue for the respondents is shown in Figure 3.1, while Figure 3.2 represents the type of facilities that are typically constructed by the respondents. Under the category of "Other," two of the respondents identified institutional work, while a third respondent identified educational work as being typically constructed.

Of the constructors surveyed, 62% claimed to provide general contracting services, while the remaining 38% were specialty contractors. The specialties

listed by constructors include CSI Divisions 3 (Concrete), 9 (Finishes), 15 (Mechanical), and 16 (Electrical).

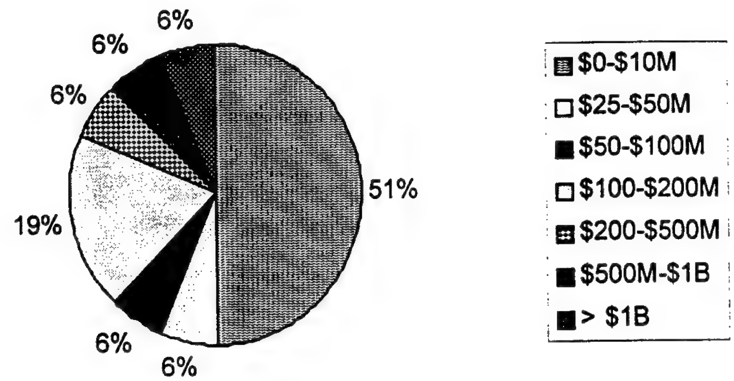

Figure 3.1 Annual Revenue

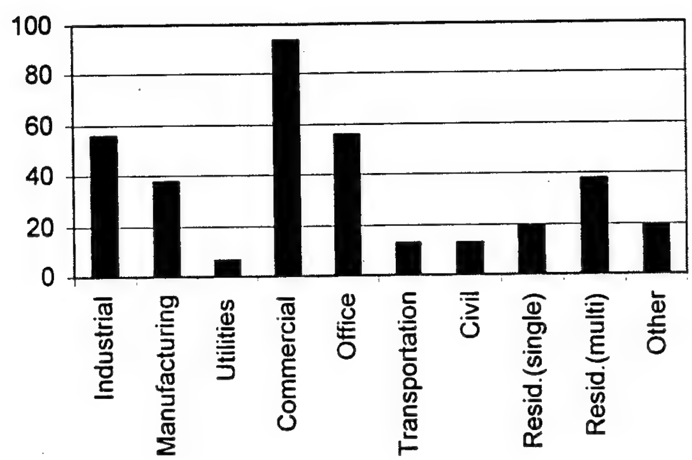

Figure 3.2 Facilities Constructed

The distribution of public versus private work is shown in Figure 3.3; these values are averages. The median for public work is 62.5 percent, while the median for private work is 37.5 percent. The distribution for type of work performed by the constructors is shown in Figure 3.4.

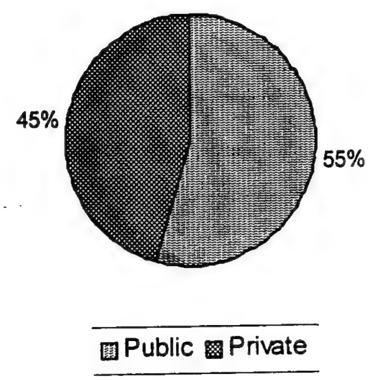

Figure 3.3 Public/Private Distribution

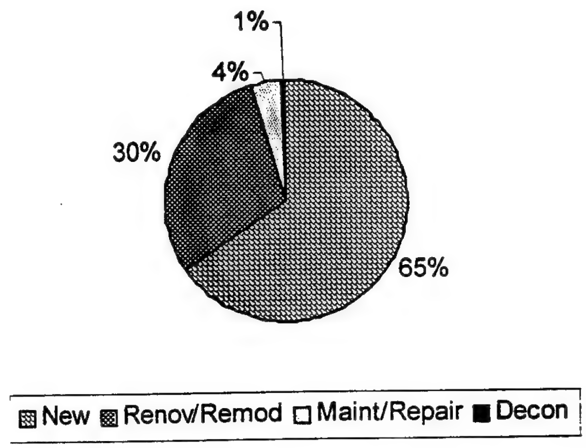

Figure 3.4 Type of Work Constructed

3.2.2 Designer Profiles

The designer respondents were presidents, managers, or engineers, with an average of 21 years of experience in the construction industry and 24 years as a designer. The average annual revenue for the respondents is shown in Figure 3.5, while Figure 3.6 represents the type of facilities that are typically designed by the respondents. The other types of facilities identified for this question included institutional, educational, mining, bridges, water and wastewater treatment and public agency projects. The types of design services provided by the respondents are shown in Figure 3.7. Respondents identified communications, roofing/waterproofing and planning & environmental as design services that were not specifically listed.

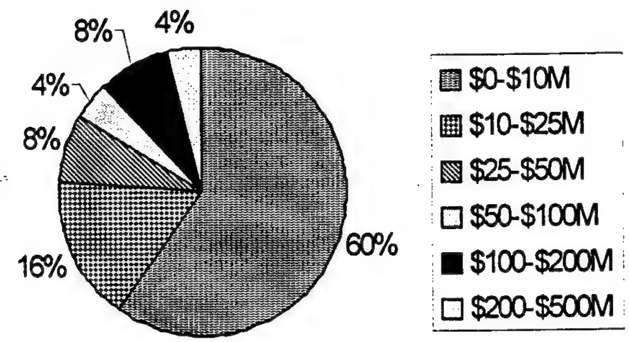

Figure 3.5 Annual Billings

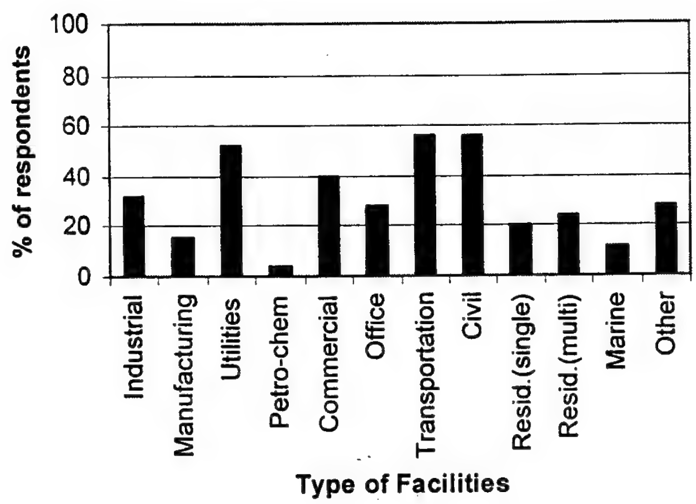

Figure 3.6 Facilities Designed

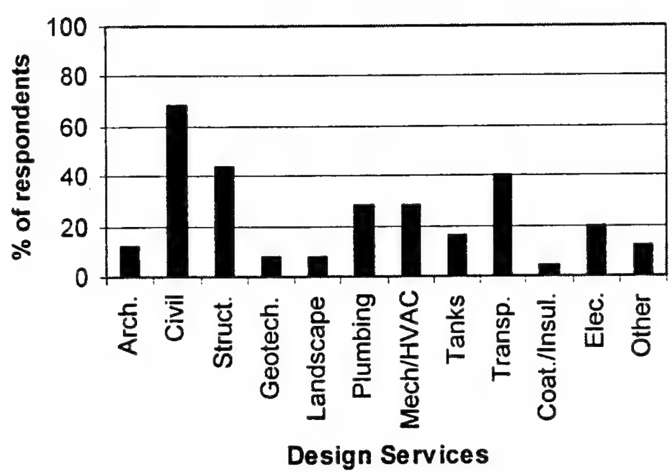

Figure 3.7 Design Services Provided

The distribution of public versus private work is shown in Figure 3.8; these values are averages. The median for public work is 70 percent, while the median for private work is 30 percent. The distribution for type of work performed by the designers is shown in Figure 3.9.

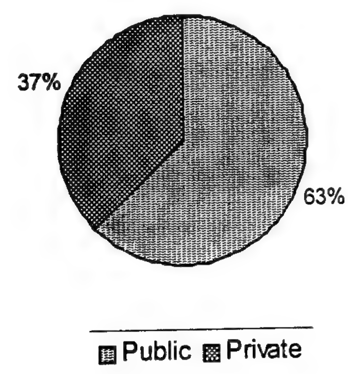

Figure 3.8 Public/Private Distribution

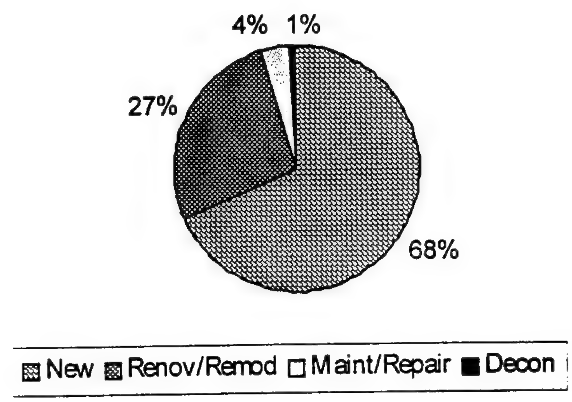

Figure 3.9 Type of Work Designed

3.3 Life Cycle Properties-Current Practices

The first section of current practices questioned respondents on which life cycle properties their companies or firms formally considered. They were also asked to rank those properties in terms of importance, with 1 being highest. The next series of questions asked the respondents to identify how life cycle properties are formally addressed, the stage of a project in which the life cycle properties are formally addressed and how the companies or firms measured the effectiveness of addressing life cycle properties. They were asked to consider only those properties that they had previously identified as being formally addressed.

3.3.1 Ranking of Life Cycle Properties

For constructors, it was clear from the data that constructability was their highest priority. If tallied by average, then the order would be constructability, maintainability, designability, operability, reconstructability and deconstructability. This is shown in Table 3.1. Because the respondents were not required to rank all of the properties, only those which they formally addressed, there aren't enough data points to differentiate between some of the properties. Designability and maintainability received lower scores than constructability, but it is difficult to prioritize one over the other. Such is the case with operability and reconstructability. These two properties are ranked lower than designability and maintainability, but it is difficult to identify one as more important. Deconstructability was clearly ranked last, with the lowest rankings and the least consideration.

For designers, there is no clear single property that is most important. If tallied by average, then the order would be constructability, operability, designability, maintainability, reconstructability and deconstructability. The comparison between the constructor responses and the designers responses is shown in Table 3.1. Just as with the constructor responses, there aren't enough data points to clearly differentiate between some of the properties. Constructability and operability were both important and had similar values. Designability and maintainability followed with similar values. Reconstructability and deconstructability were least important. It does appear that reconstructability is more important than deconstructability due to the number of firms that formally consider this property.

Table 3.1 Life Cycle Property Rankings (By Average)

Rank	Constructors	Designers
1	Constructability	Constructability
2	Maintainability	Operability
3	Designability	Designability
4	Operability	Maintainability
5	Reconstructability	Reconstructability
6	Deconstructability	Deconstructability

3.3.2 Addressing Life Cycle Properties

The next question asked the respondents to identify the mechanisms that their companies or firms use to address the life cycle properties that they formally address. The choices included value engineering, constructability reviews, project team meetings, company project/design manuals or other. Designers QA/QC reviews, use of agency standards, use of O&M manuals and concept and criteria reviews as other measures used. The second question asked respondents to identify at which stage during the project the life cycle properties are formally addressed. The choices included planning, preliminary engineering, design, construction, operation & maintenance and reconstruction/demolition.

The final question in this section asked how the companies or firms measured the success of addressing the life cycle properties. The choices for constructors included no monitoring measures used, pre-construction job costs, pre-construction staffing, final construction cost, construction staffing, contract change orders, requests for information, project schedule, designer feedback, owner feedback and other (value engineering issues was the only other response noted). For designers, the choices included no monitoring measures used, design services billings, design staffing, construction cost, construction support

billings, construction support staffing, contract change orders, contractor requests for information, contractor feedback, owner feedback and other. Designers identified supplier feedback and monthly reporting of project performance as other measures used. Detailed graphs of the life cycle properties and the constructors and designers responses are provided in Appendix C.

Of those respondents that formally addressed designability, constructors used value engineering and project team meetings as the primary mechanisms addressing the issue. Construction reviews and plan reviews were also used, but not to the same extent. For designers, plan reviews and project team meetings were the main practices utilized, with the other choices being used between 20% and 50% of the time. Both designers and constructors primarily addressed designability during the planning, preliminary engineering and design stages. Constructors also addressed designability during the construction stage. The measures that were used to determine effectiveness were scattered throughout the choices. For constructors, pre-construction job was cited as the leading measure, and for designers, design service billings was the leading measure.

Both constructors and designers that formally addressed constructability used value engineering, constructability reviews, plan reviews and project team meetings to address the life cycle properties. Company project/design manuals were used a small percentage of the time, as were other mechanisms. Constructors mainly addressed constructability during the construction phase, with planning, preliminary engineering and design stages also being important. Designers addressed constructability during the design stage, with preliminary engineering and planning being important. These responses appear reasonable, as the constructor does not have as much input during the earlier phases of a project's life cycle, as do designers. As with designability, the measures used to

determine the effectiveness of addressing the life cycle properties were scattered throughout the choices. The final construction cost is used most often by constructors to measure effectiveness, while the designers rely on the construction costs as well as contractor feedback.

Of those respondents formally addressing maintainability, constructors stated that they used all of the methods identified, with constructability reviews and project team meetings being used slightly more than value engineering and plan reviews. Designers use plan reviews and project team meetings, with value engineering, constructability reviews and other mechanisms used to a lesser degree. The constructor data shows that maintainability is being addressed throughout the various stages of a project, with the obvious exception of reconstruction/demolition. The designers indicated that maintainability is addressed most often during the design stage, with preliminary engineering and construction following. Maintainability was also addressed during the other stages to a lesser degree. For both constructors and designers, the owner feedback is the primary measure used to determine the effectiveness of addressing maintainability. Because owner feedback is a more passive measure, it appears that maintainability is not being measured as effectively as designability or constructability.

The responses for addressing operability were very similar to the responses for maintainability. Constructors used pre-construction job costs as a measure of effectiveness, as well as owner feedback. Designers addressed operability during preliminary engineering and planning more than maintainability.

The constructors who formally addressed reconstructability used various mechanisms. Value engineering, constructability reviews, plan reviews and project team meetings were all identified as mechanisms. Designers primarily use project team meetings to address reconstructability. Constructors address

reconstructability during the design phase, planning, and during reconstruction/ demolition of the facility. Designers address reconstructability during the design and preliminary engineering stages, with some consideration during the planning and construction stages. Constructors use various measures to determine effectiveness including pre-construction job costs, pre-construction staffing, designer feedback and owner feedback. Designers rely primarily on owner feedback to determine effectiveness, with some using no monitoring measures or contractor feedback.

Deconstruction was only formally considered by 2 constructors and 1 designer. Because of the extremely limited data, it is difficult to identify any trends in this data set.

A summary of the current practices of both constructors and designers is shown in Table 3.2.

Table 3.2 Life Cycle Properties Current Practices

Property	Respondent Group	Mechanism	Phase	Measure
Designability	Constructors	Value Engineering Team Meetings	Planning Preliminary Engineering Design	Pre-construction Job Costs Owner Feedback
	Designers	Team Meetings Plan Reviews	Preliminary Engineering Planning	Design Services Billings
Constructability	Constructors	Constructability Reviews Plan Reviews	Construction Planning	Final Construction Cost
	Designers	Plan Reviews Constructability Reviews Team Meetings	Design Preliminary Engineering	Construction Cost Contractor Feedback
Maintainability	Constructors	Constructability Reviews Team Meetings	Planning Design Construction	Owner Feedback Pre-construction Job Costs
	Designers	Plan Reviews Team Meetings	Design	Owner Feedback

Table 3.2 Life Cycle Properties Current Practices (cont.)

Property	Respondent Group	Mechanism	Phase	Measure
Operability	Constructors	Value Engineering Plan Reviews Team Meetings	Design	Pre-construction Job Costs Owner Feedback
	Designers	Plan Reviews Team Meetings	Design Preliminary Engineering Planning	Owner Feedback
Reconstructability	Constructors	Team Meetings	Design	Pre-construction Job Costs Pre-construction Staffing Designer Feedback Owner Feedback
	Designers	Team Meetings	Design Preliminary Engineering	Owner Feedback
Deconstructability	Constructors	Value Engineering Constructability Reviews Team Meetings Other	Design Reconstruction/Demolition	None Final Construction Cost
	Designers	Team Meetings	Design	Design Staffing

3.4 Life Cycle Properties-Industry Needs

3.4.1 Ranking of Life Cycle Properties

This section of the survey asked the respondents to rank all of the life cycle properties in the order of importance to success in achieving maximum value in the constructed facility. The respondents were then questioned on whom they felt should be responsible for addressing each of the life cycle properties. The choices included owner, designer, constructor, construction manager, all of the parties, none of the parties, or other. One respondent identified banks and lenders as a responsible party under the other category. There were two constructor surveys and seven designer surveys that did not rank all six of the properties. There are two possible explanations for this, the respondents either didn't understand the question, or else they did not feel that all of the properties were important enough to be formally addressed in achieving maximum value in the facility. It is impossible to know which of these two alternatives is more accurate. Three constructors and five of the designers marked particular parties as being responsible as well as all parties responsible for a specific property. It is assumed that these respondents felt that individual parties should have responsibility, but that general awareness by all parties is important. Experiences with partnering may have fueled this particular type of response.

For constructors, the ranking of the properties, based on an average would yield the following order of importance: constructability, operability, maintainability, designability, reconstructability and deconstructability. It is evident that constructability is deemed the most important factor. There is very little difference between operability and maintainability, and given the limited amount of data points, it is difficult to identify one as more important than the other. For designers, the ranking by average would be operability, constructability, maintainability, designability, reconstructability and deconstructability. The data

is very similar for operability and constructability, so it is difficult to identify a trend in these properties. Table 3.3 shows a comparison of the constructors and designers responses.

Table 3.3 Industry Importance Rankings (By Average)

Rank	Constructors	Designers
1	Constructability	Operability
2	Operability	Constructability
3	Maintainability	Maintainability
4	Designability	Designability
5	Reconstructability	Reconstructability
6	Deconstructability	Deconstructability

3.4.2 Parties Responsible for Life Cycle Properties

The second part of this section asked the respondents to identify who they felt should be responsible for the individual life cycle properties. Choices included owner, designer, constructor, construction manager, all parties, none of the parties and other (there were no other responses). Graphs showing the results are included in Appendix D. The responses for constructors and designers were similar for all of the properties. There were slight variations, but the trends were very similar.

For designability, the consensus is that the designer is responsible. Other parties have some responsibility, but not as much as the designer. For constructability, the designer, constructor, and the construction manager were all identified as having responsibility, while the owner or all parties held a lesser degree of responsibility. The owner and designer were most responsible for maintainability, while the constructor and contract manager had an equal degree of responsibility. The parties responsible for operability were the same as for maintainability. Reconstructability and deconstructability also had similar

responses. Both constructors and designers identified the owners and designers as having primary responsibility.

3.4.3 Survey Comments

Survey respondents were asked to identify any trends they see having an impact on their firm or company in the next five to ten years. They were also asked to provide specific examples or methods of addressing the life cycle properties on past projects.

Table 3.4 shows the methods of addressing life cycle properties as given in the survey and a summarization of the additional methods identified by constructors and designers for the life cycle property of designability. One designer identified permitability as being a factor that affects project costs and considerations. This property may initially be included as an aspect of designability. Another respondent noted a trend toward designing buildings with life cycles of less than 20 years. This measure may have the impact of bringing the latter life cycle phases into sharper focus, thus facilitating more realistic evaluations.

Table 3.4 Designability Comments

Survey Options	**Constructor Comments**	**Designer Comments**
• Value engineering • Constuctability reviews • Plan reviews • Project team meetings • Company project/ design manuals	• Company reports • Repetitive systems • Work with designer/ architect	• Cost estimating • Management of project (design) costs • Accepted design procedures

The methods used for addressing constructability are summarized in Table 3.5. Among the trends identified by constructors as impacting constructability, an emphasis on extracting lessons learned form past projects and applying that to new projects is also apparent in the literature (East and Fu 1996; Kartam 1996; Krizek et al 1996).

Table 3.5 Constructability Comments

Survey Options	**Constructor Comments**	**Designer Comments**
• Value engineering • Constuctability reviews • Plan reviews • Project team meetings • Company project/ design manuals	• Lessons learned • Studying documents • Continual review of design documents • Standard design and construction techniques • Complete/formal analysis/review of each project	• Reviews by experienced managers • Discussions with constructors/ fabricators • Involving construction partner in reviews • Phasing identified on contract documents • Design staff involved during construction phase

Table 3.6 is a summarization of the additional methods used to address maintainability, by both constructors and designers. One comment, by a constructor, mentioned the expectation that over valuing first cost as compared to life cycle costs would continue. This comment indicates the perception of a persisting lack of recognition by owners of the magnitude on operations and maintenance (O&M) costs versus the design and construction costs. Arditi and Gunaydin (1998), however, found in their survey that some practitioners do recognize that quality in the O&M phase bay be enhanced by early planning of the O&M budget. The practice of such planning would facilitate a more critical examination of the operability and maintainability of a design. However, as long

as the low-bid design-bid-build project delivery system remains the most prevalent, the emphasis on first cost will likely continue. Another respondent identified "Risks of new products, components" as a trend affecting maintainability. Williamson (1996) also cited this as a basic issue of maintainability of the building envelope. Designer comments concurred with those of constructors.

Table 3.6 Maintainability Comments

Survey Options	**Constructor Comments**	**Designer Comments**
• Value engineering • Constuctability reviews • Plan reviews • Project team meetings • Company project/ design manuals	• Recommendations to owners • Systems review with owner	• Equipment supplier/client review • Operations staff review • Follow up after one year • Keep it simple • Input from maintenance personnel • Show maintenance access spaces on plans

The methods used for addressing operability are summarized in Table 3.7. In addition to the methods addressed in the table, the trends affecting operability are similar to those affecting maintainability. One designer commented on operability being related to an owner's productivity. This expected impact puts an important perspective on operability. Designers already have to understand functional requirements to some degree, but increased emphasis on the owner's productivity may significantly impact the process of design development. Greater knowledge of the owner's enterprise will be required.

Figure 3.7 Operability Comments

Survey Options	Constructor Comments	Designer Comments
• Value engineering • Constuctability reviews • Plan reviews • Project team meetings • Company project/ design manuals	• Recommendations to owners • Understanding the owners requirements	• Client/operations staff reviews • Input from maintenance personnel • Know what you design • Follow up after one year • Detailed sequences of operation narratives

Table 3.8 summarizes the additional methods used to address reconstructability and deconstructability, by both constructors and designers. There were very few comments on these two properties. One designer addressed concern due to the lack of complete as-constructed plans increasing the liability risks. This is a critical reason to be concerned about this property, and is also a parameter that impacts the property.

Table 3.8 Reconstructability/Deconstructability Comments

Survey Options	Constructor Comments	Designer Comments
• Value engineering • Constuctability reviews • Plan reviews • Project team meetings • Company project/ design manuals	• Rarely considered	• Equipment supplier review • Complete layout of future work

Some of the other trends that were identified by constructors and designers affected the entire life cycle of a facility, not a single property. One constructor stated that designers are "relying more in builders to sort out [life cycle] issues, rather than truly evaluating these matters during [the] design process." This is an interesting commentary in an industry climate where there is so much talk of integration that this notion of shifting responsibility persists.

Noted trends further emphasizing the importance of the life cycle perspective included "recycling of building material and components," and "flexibility of building for unknown future uses." One respondent also stated that owners are "demanding more flexibility and efficiency in their facility." Another comment identified "a strong trend toward faster, more efficient, and cost effective construction as owners (particularly in the hi-tech sector) need facilities immediately." This makes it all the more important that there is a rational approach that considers the life cycle quality of new facilities.

One constructor identified concern over understanding "what the owner 'thinks' his goals of the project are..." This respondent also identified a difference between long term owner occupied buildings and specialty developers who will sell the project within one to two years. The owner's occupancy interests will conceivably be the biggest driver in determining the owner's interest in total life cycle quality.

Design-build was noted numerous times by designers as a trend having impacts that would relate to life cycle properties, but no respondents explained how they saw this relation, or the direct impact to the life cycle properties of design-build projects.

Finally, one comment from a constructor regarding trends truly underscored the rationale for this study: "Failure by owners to recognize and plan for replacement

of facilities prior to the end of their useful life is causing a shift in emphasis from new construction to rehab and replacement." It is expected that the incorporation of such considerations in initial planning will greatly enhance efforts in the reconstruction and deconstruction phases.

CHAPTER 4 CONCLUSIONS

The goal of this research project was to identify, from the perspectives of constructors and designers, how life cycle properties are being addressed by the industry, how effectiveness is measured, and who should be responsible for the different life cycle properties. The following are specific conclusions based on the survey results:

- Both constructors and designers ranked the life cycle properties similarly, with operability and maintainability reversed in the two populations; constructors ranked maintainability higher, while designers ranked operability higher.
- Both of these groups also ranked the importance of the life cycle properties to the industry, in general, in a comparable manner, with constructability and operability being reversed in the two populations; constructors ranked constructability higher than operability, while designers had these two properties reversed.
- Team meetings, plan reviews and constructability reviews were important mechanisms for addressing the various life cycle properties, throughout the constructor and designer populations.
- Planning, preliminary engineering and design phases were when most constructors and designers were addressing the life cycle properties.
- The measures used to determine the effectiveness of addressing the life cycle properties varies among the constructor and designer segments, although owner feedback was utilized most often. It is noted that constructors tended to utilize a wider variety of measures than designers.
- Reconstruction and deconstruction were not addressed by these two groups. It is expected that owners and professional construction managers may have more concern for these phases.
- Constructors and designers had similar opinions on which parties should be responsible for the respective life cycle properties, however there was typically more than one party important for the life cycle properties. This may indicate a need for shared responsibility throughout the life cycle properties.

The disparity in responses indicates that more effort needs to be spent on developing mechanisms to address the life cycle properties, as well as monitoring the effectiveness of these mechanisms. In order to develop these mechanisms, it is imperative that consensus be reached on who is responsible for considering the various life cycle properties before the mechanisms can be developed.

Additional examination of the questions addressed in this survey will include owners and professional construction managers, as well as another geographic region. A more complete representation of the construction industry will provide a basis for more research on each life cycle property.

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Appendix A Constructor and Designer Surveys

LIFE CYCLE PROPERTY SURVEY OF CONSTRUCTORS

Please refer to the following definitions when answering the survey questions.

Designability: A property that reflects the ease of designing and engineering a proposed project scope.

Constructability: A property that reflects the ease of construction of a project's design and the clarity and completeness of a project's contract documents.

Operability: A property that reflects the accessibility, functionality, and ease of manipulation and control of all operable systems in a facility.

Maintainability: A property that reflects the reliability and ease of servicing, repair and replacement of any active and passive systems in a facility.

Reconstructability: A property that reflects the ease of modifying or augmenting a facility to meet a future alternative or expanded functional requirement.

Deconstructability: A property that reflects the ease of dismantling and removing a facility or system in a facility so that the facility no longer meets its originally intended purpose.

If you have a preferred definition for any of the life cycle properties that differs in essence from those given above, please provide such definitions below.

Designability: ____________________

Constructability: ____________________

Maintainability: ____________________

Operability: ____________________

Reconstructability: ____________________

Deconstructability: ____________________

Description of you and your firm

1. What is your job title: ____________________

2. How many **years** of experience do you have
   - in the construction industry: ______
   - as a constructor: ______

3. What is your firm's approximate **annual** revenue?
   - ☐ $0 to $10 million
   - ☐ $10 to $25 million
   - ☐ $25 to $50 million
   - ☐ $50 to $100 million
   - ☐ $100 to $200 million
   - ☐ $200 to $500 million
   - ☐ $500 million to $1 billion
   - ☐ more than $1 billion

4. What type(s) of facilities does your firm **typically** construct?
   - ☐ Industrial
   - ☐ Manufacturing
   - ☐ Utilities
   - ☐ Petro-chemical
   - ☐ Commercial
   - ☐ Office
   - ☐ Transportation
   - ☐ Civil
   - ☐ Residential (single family)
   - ☐ Residential (multi-family)
   - ☐ Marine
   - ☐ Other: ____________

5. What construction service(s) does your firm provide?
   - ☐ General contracting   CSI division: ____________________
   - ☐ Specialty contracting   CSI division: ____________________

6. What is the approximate **percentage** distribution between public and private work constructed by your firm?

   ______ % Public   ______ % Private

7. What is the approximate **percentage** distribution of the type of work constructed by your firm?

   ______ % New constr.   ______ % Renov./remodel.   ______ % Maint./repair

   ______ % Deconstruction/demolition

Assessment of current practice regarding life cycle properties

8. Which life cycle properties are **formally** considered by your firm? Select all that apply.
   - ☐ Designability
   - ☐ Constructability
   - ☐ Maintainability
   - ☐ Operability
   - ☐ Reconstructability
   - ☐ Deconstructability

9. For **only** the life cycle properties you noted in Question 8, **rank** those properties in the order of importance to the constructed facility. Please respond with 1 being the most important and ascending numbers representing decreasing importance.

   ______ Designability   ______ Operability

   ______ Constructability   ______ Reconstructability

   ______ Maintainability   ______ Deconstructability

Please answer the following questions by putting an X in the box below the appropriate life cycle property.	Designability	Constructability	Maintainability	Operability	Reconstructability	Deconstructability
10. By what practice(s) does your firm address the properties you noted in Question 8?						
Value engineering	☐	☐	☐	☐	☐	☐
Constructability reviews	☐	☐	☐	☐	☐	☐
Plan reviews	☐	☐	☐	☐	☐	☐
Project team meetings	☐	☐	☐	☐	☐	☐
Company project manuals	☐	☐	☐	☐	☐	☐
Other: ____________	☐	☐	☐	☐	☐	☐
11. At what point(s) in a project does your firm typically address the properties you noted in Question 8?						
Planning	☐	☐	☐	☐	☐	☐
Preliminary Engineering	☐	☐	☐	☐	☐	☐
Design	☐	☐	☐	☐	☐	☐
Construction	☐	☐	☐	☐	☐	☐
Operation and Maintenance	☐	☐	☐	☐	☐	☐
Reconstruction/Demolition	☐	☐	☐	☐	☐	☐
12. On a project, how does your firm measure the extent to which it has successfully addressed the properties you noted in Question 8?						
No monitoring measures used	☐	☐	☐	☐	☐	☐
Pre-construction job costs	☐	☐	☐	☐	☐	☐
Pre-construction staffing	☐	☐	☐	☐	☐	☐
Final construction cost	☐	☐	☐	☐	☐	☐
Construction staffing	☐	☐	☐	☐	☐	☐
Contract change orders	☐	☐	☐	☐	☐	☐
Requests for information	☐	☐	☐	☐	☐	☐
Project schedule	☐	☐	☐	☐	☐	☐
Designer feedback	☐	☐	☐	☐	☐	☐
Owner feedback	☐	☐	☐	☐	☐	☐
Other: ____________	☐	☐	☐	☐	☐	☐

Assessment of industry needs regarding life cycle properties

13. Considering all of the life cycle properties, **rank** the properties in the order of importance to success in achieving maximum value in the constructed facility. Please respond with 1 being the most important and 6 the least important.

______ Designability	______ Operability
______ Constructability	______ Reconstructability
______ Maintainability	______ Deconstructability

Please answer the following question by putting an X in the box below the appropriate life cycle property.	Designability	Constructability	Maintainability	Operability	Reconstructability	Deconstructability
14. Which party(ies) to the project team should address each of the life cycle properties?						
Owner	☐	☐	☐	☐	☐	☐
Designer	☐	☐	☐	☐	☐	☐
Constructor	☐	☐	☐	☐	☐	☐
Construction Manager	☐	☐	☐	☐	☐	☐
All of the parties listed above	☐	☐	☐	☐	☐	☐
None of the parties listed above	☐	☐	☐	☐	☐	☐
Other: ______________	☐	☐	☐	☐	☐	☐

15. What trends relating to specific life cycle properties do you see impacting your firm in the next 5 to 10 years? Please continue on the back of this sheet if more room is required.

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16. Please provide any specific examples or methods of how you have addressed the life cycle properties on past projects.

Designability: ______________________________

Constructability: ______________________________

Maintainability: ______________________________

Operability: ______________________________

Reconstructability: ______________________________

Deconstructability: ______________________________

Summary report and follow-up interview

If you would like a copy of the study summary report, please provide the following information. **All of your responses will remain confidential.**

Name: ______________________________
Company: ______________________________
Street: ______________________________
City: ______________ State: ______ Zip: ________

If you are available for a short telephone interview to further discuss the life cycle properties and related issues, please provide your telephone number: ______________

LIFE CYCLE PROPERTY SURVEY OF DESIGNERS

Please refer to the following definitions when answering the survey questions.

Designability: A property that reflects the ease of designing and engineering a proposed project scope.

Constructability: A property that reflects the ease of construction of a project's design and the clarity and completeness of a project's contract documents.

Operability: A property that reflects the accessibility, functionality, and ease of manipulation and control of all operable systems in a facility.

Maintainability: A property that reflects the reliability and ease of servicing, repair and replacement of any active and passive systems in a facility.

Reconstructability: A property that reflects the ease of modifying or augmenting a facility to meet a future alternative or expanded functional requirement.

Deconstructability: A property that reflects the ease of dismantling and removing a facility or system in a facility so that the facility no longer meets its originally intended purpose.

If you have a preferred definition for any of the life cycle properties that differs in essence from those given above, please provide such definitions below.

Designability: ______________________________

Constructability: ______________________________

Maintainability: ______________________________

Operability: ______________________________

Reconstructability: ______________________________

Deconstructability: ______________________________

Description of you and your firm

1. What is your job title: ______________________________

2. How many **years** of experience do you have
   - in the construction industry: ______
   - as a designer: ______

3. What are your firm's approximate **annual billings** for design services?
   - ☐ $0 to $5 million
   - ☐ $5 to $10 million
   - ☐ $10 to $15 million
   - ☐ $15 to $25 million
   - ☐ $25 to $50 million
   - ☐ $50 to $100 million
   - ☐ $100 to $500 million
   - ☐ more than $500 million

4. What type(s) of facilities does your firm **typically** design?
   - ☐ Industrial
   - ☐ Manufacturing
   - ☐ Utilities
   - ☐ Petro-chemical
   - ☐ Commercial
   - ☐ Office
   - ☐ Transportation
   - ☐ Civil
   - ☐ Residential (single family)
   - ☐ Residential (multi-family)
   - ☐ Marine
   - ☐ Other: ______________

5. What design service(s) does your firm provide?
   - ☐ Architectural
   - ☐ Civil
   - ☐ Structural
   - ☐ Geotechnical
   - ☐ Landscape
   - ☐ Piping/Plumbing
   - ☐ Mechanical/HVAC
   - ☐ Tanks/Vessels
   - ☐ Traffic/Transportation
   - ☐ Coatings/Insulation
   - ☐ Electrical/Instrumentation
   - ☐ Other: ______________

6. What is the approximate **percentage** distribution between public and private work designed by your firm?

   ______ % Public ______ % Private

7. What is the approximate **percentage** distribution of the type of work designed by your firm?

   ______ % New constr. ______ % Renov./remodel. ______ % Maint./repair

   ______ % Deconstruction/demolition

Assessment of current practice regarding life cycle properties

8. Which life cycle properties are **formally** considered by your firm? Select all that apply.
   - ☐ Designability
   - ☐ Constructability
   - ☐ Maintainability
   - ☐ Operability
   - ☐ Reconstructability
   - ☐ Deconstructability

9. For **only** the life cycle properties you noted in Question 8, **rank** those properties in the order of importance to the constructed facility. Please respond with 1 being the most important and ascending numbers representing decreasing importance.

   ______ Designability ______ Operability

   ______ Constructability ______ Reconstructability

   ______ Maintainability ______ Deconstructability

Please answer the following questions by putting an X in the box below the appropriate life cycle property.	Designability	Constructability	Maintainability	Operability	Reconstructability	Deconstructability
10. By what practice(s) does your firm address the properties you noted in Question 8?						
Value engineering	☐	☐	☐	☐	☐	☐
Constructability reviews	☐	☐	☐	☐	☐	☐
Plan reviews	☐	☐	☐	☐	☐	☐
Project team meetings	☐	☐	☐	☐	☐	☐
Company design manuals	☐	☐	☐	☐	☐	☐
Other: ____________	☐	☐	☐	☐	☐	☐
11. At what point(s) in a project does your firm typically address the properties you noted in Question 8?						
Planning	☐	☐	☐	☐	☐	☐
Preliminary Engineering	☐	☐	☐	☐	☐	☐
Design	☐	☐	☐	☐	☐	☐
Construction	☐	☐	☐	☐	☐	☐
Operation and Maintenance	☐	☐	☐	☐	☐	☐
Reconstruction/Demolition	☐	☐	☐	☐	☐	☐
12. On a project, how does your firm measure the extent to which it has successfully addressed the properties you noted in Question 8?						
No monitoring measures used	☐	☐	☐	☐	☐	☐
Design services billings	☐	☐	☐	☐	☐	☐
Design staffing	☐	☐	☐	☐	☐	☐
Construction cost	☐	☐	☐	☐	☐	☐
Construction support billings	☐	☐	☐	☐	☐	☐
Construction support staffing	☐	☐	☐	☐	☐	☐
Contract change orders	☐	☐	☐	☐	☐	☐
Contractor requests for information	☐	☐	☐	☐	☐	☐
Contractor feedback	☐	☐	☐	☐	☐	☐
Owner feedback	☐	☐	☐	☐	☐	☐
Other: ____________	☐	☐	☐	☐	☐	☐

Assessment of industry needs regarding life cycle properties

13. Considering all of the life cycle properties, **rank** the properties in the order of importance to success in achieving maximum value in the constructed facility. Please respond with 1 being the most important and 6 the least important.

______	Designability	______	Operability
______	Constructability	______	Reconstructability
______	Maintainability	______	Deconstructability

Please answer the following question by putting an X in the box below the appropriate life cycle property.	Designability	Constructability	Maintainability	Operability	Reconstructability	Deconstructability
14. Which party(ies) to the project team should address each of the life cycle properties?						
Owner	☐	☐	☐	☐	☐	☐
Designer	☐	☐	☐	☐	☐	☐
Constructor	☐	☐	☐	☐	☐	☐
Construction Manager	☐	☐	☐	☐	☐	☐
All of the parties listed above	☐	☐	☐	☐	☐	☐
None of the parties listed above	☐	☐	☐	☐	☐	☐
Other: ______________	☐	☐	☐	☐	☐	☐

15. What trends relating to specific life cycle properties do you see impacting your firm in the next 5 to 10 years? Please continue on the back of this sheet if more room is required.

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16. Please provide any specific examples or methods of how you have addressed the life cycle properties on past projects.

Designability: ______________________________

Constructability: ______________________________

Maintainability: ______________________________

Operability: ______________________________

Reconstructability: ______________________________

Deconstructability: ______________________________

Summary report and follow-up interview

If you would like a copy of the study summary report, please provide the following information. **All of your responses will remain confidential.**

Name: ______________________________
Company: ______________________________
Street: ______________________________
City: ______________ State: ______ Zip: ________

If you are available for a short telephone interview to further discuss the life cycle properties and related issues, please provide your telephone number: ______________

Appendix B Constructor and Designer Responses

The following abbreviations were used in this appendix:

Annual Revenue (Constructors)
- 1 = $0-$10 million
- 2 = $10-$25 million
- 3 = $25-$50 million
- 4 = $50-$100 million
- 5 = $100-$200 million
- 6 = $200-$500 million
- 7 = $500-$1 billion
- 8 = more than $1 billion

Annual Billings (Designers)
- 1 = $0-$5 million
- 2 = $5-$10 million
- 3 = $10-$15 million
- 4 = $15-$25 million
- 5 = $25-$50 million
- 6 = $50-$100 million
- 7 = $100-$500 million
- 8 = more than $500 million

Facilities Constructed/Designed
- 1 = Industrial
- 2 = Manufacturing
- 3 = Utilities
- 4 = Petro-Chemical
- 5 = Commercial
- 6 = Office
- 7 = Transportation
- 8 = Civil
- 9 = Residential (single family)
- 10 = Residential (multi-family)
- 11 = Marine
- 12 = Other

Design Services (Designers)
- 1 = Architectural
- 2 = civil
- 3 = Structural
- 4 = Geotechnical
- 5 = Landscape
- 6 = Piping/Plumbing
- 7 = Mechanical/HVAC
- 8 = Tanks/Vessels
- 9 = Traffic/Transportation
- 10 = Coatings/Insulation
- 11 = Electrical/Instrumentation
- 12 = Other

Mechanism (Both)
- VE = Value Engineering
- CON = Constructability Reviews
- PLAN = Plan Reviews
- MEET = Project Team Meetings
- MAN = Company Manuals
- OTH = Other

Project Stage (Both)
- PLAN = Planning
- PRE = Preliminary Engineering
- DES = Design
- CON = Construction
- O&M = Operations & Maintenance
- DEMO = Reconstruction/Demolition

Effectiveness Measures (Constructors)
- NONE = No monitoring used
- PRE$ = Preconstruction job costs
- PRESTF = Preconstruction staffing
- CON$ = Final construction cost
- CONSTF = Construction staffing
- CO = Contract change orders
- RFI = Request for information
- SCHED = Project schedule
- DES = Designer feedback

OWN = Owner Feedback
OTH = Other

Effectiveness Measures (Designers)
NONE = No monitoring used
DES$ = Design services billings
DESSTF = Design staffing
CON$ = Construction cost
CONSP$ = Construction support billings
CONSTF = Construction support staffing
CO = Contract change orders
RFI = Request for information
CONFD = Contractor feedback
OWN = Owner feedback
OTH = Other

Additional Note:
In the Responsibilities portion of the following tables, there are several "o" markings. These indicate where the respondent marked individual parties as having primary responsibility, but also marked all parties as responsible.

Table B.1 Constructor Responses

Survey Number	Title	Years Exp. Industry	Years Exp. Constructor	Annual Revenue	Types of Facilities Constructed	Services General	Services Specialty	% Public	% Private	% New	% Renov/Remod	% M/R	% Decon	Designability Rank	Mechanism VE	Mechanism CON	Mechanism PLAN	Mechanism MEET	Mechanism MAN	Mechanism OTH
1	President	23	15	1	5,12	x		95	5		100									
2	President	30	30	1	1,5,10	x		65	35	50	40	10								
3	President	23	23	5	1,2,5,6,10	x		10	90	90	10			2	x			x		
4	Secretary	20		1	5		x	80	20	30	50	20		4					x	
5	VP/Operations Manager	32	33	8	5,6,12	x														
6	Asst. District Manager	14	14	5	5,6,10		x	80	20	95	5			2	x	x				
7	Admin. & Controls Manager	25	25	6	7,8	x		80	20	80	20			2	x	x	x	x		
8	President	30	30	5	2,5,6	x			100	97	3									
9	VP Operations	20	20	4	2,5,6	x			100	80	16	2	2	2	x	x	x	x		
10	President/CEO	30	30	1	1,5,9,10		x	10	90	95	2	3								
11	Director of Business Develop.	30	30	7	1,2,3,5,6,7,8,10	x		60	40	70	20	5	5	4	x		x	x		
12	President	20	20	1	1,5		x	90	10	50	40	10								
13	President		30	1	1,2,5,6,9,10		x	100		75	15	10								
14	Owner/manager	21	8	1	1,5	x		95	5	15	80		5							
15	President/CEO	35	35	3	1,2,5,6,9,12		x	40	60	60	36	4								
16	President/CEO	40	34	1	1,5,6	x		33	67	80	17	2	1							

Table B.1 Constructor Responses (cont.)

	Designability (cont.)																	Constructability												
	Project Stage						Effectiveness Measures												Mechanism						Project Stage					
Survey Number	PLAN	PRE	DES	CON	O&M	DEMO	NONE	PRE$	PRESTF	CON$	CONSTF	CO	RFI	SCHED	DES	OWN	OTH	Rank	VE	CON	PLAN	MEET	MAN	OTH	PLAN	PRE	DES	CON	O&M	DEMO
1																		1		x	x	x						x		x
2																		1	x		x				x					
3	x	x	x					x	x									1	x	x	x	x	x		x	x	x	x		x
4				x				x										1					x					x		
5																		1		x	x	x				x	x	x		
6	x	x								x				x				1	x	x					x	x				
7	x	x	x	x												x	x	1	x	x	x	x			x	x	x	x		
8																														
9	x	x	x					x	x	x		x	x		x	x		1	x	x	x	x			x	x	x			
10																		1	x	x	x							x		
11			x															1	x	x	x	x	x		x	x	x	x		
12																														
13																														
14																		2						x						
15																														
16																		1	x	x	x	x			x			x		

Table B.1 Constructor Responses (cont.)

	Constructability (cont.)											Maintainability																							
	Effectiveness Measures												Mechanism						Project Stage						Effectiveness Measures										
Survey Number	NONE	PRE$	PRESTF	CON$	CONSTF	CO	RFI	SCHED	DES	OWN	OTH	Rank	VE	CON	PLAN	MEET	MAN	OTH	PLAN	PRE	DES	CON	O&M	DEMO	NONE	PRE$	PRESTF	CON$	CONSTF	CO	RFI	SCHED	DES	OWN	OTH
1				x	x	x	x	x																											
2										x		2		x		x			x															x	
3		x	x	x	x	x		x	x	x																									
4		x		x	x	x	x	x				2					x					x				x		x	x	x	x	x			
5									x	x																									
6				x				x																											
7										x	x	4	x	x	x	x	x		x	x	x	x	x											x	
8																																			
9		x	x	x		x	x		x	x		3	x	x	x	x			x	x	x					x	x						x	x	
10		x		x	x		x	x																											
11				x	x	x	x		x	x		2	x	x	x	x					x	x	x		x										
12																																			
13																																			
14				x																															
15																																			
16		x	x	x	x		x	x																											

Table B.1 Constructor Responses (cont.)

Survey Number	Operability																									Reconstructability						
		Mechanism						Project Stage						Effectiveness Measures													Mechanism					
	Rank	VE	CON	PLAN	MEET	MAN	OTH	PLAN	PRE	DES	CON	O&M	DEMO	NONE	PRE$	PRESTF	CON$	CONSTF	CO	RFI	SCHED	DES	OWN	OTH	Rank	VE	CON	PLAN	MEET	MAN	OTH
1																															
2																															
3	3	x		x	x	x		x	x	x	x		x		x	x			x	x			x		4	x		x	x		
4	3					x						x			x																
5																									2			x	x		
6																															
7	3	x	x	x	x	x		x	x	x	x	x											x								
8																															
9	4	x	x	x	x			x	x	x					x	x						x	x		5	x	x	x	x		
10																															
11	3	x	x	x	x					x	x	x		x											5	x	x		x		
12																															
13																															
14																									1						x
15																															
16																															

Table B.1 Constructor Responses (cont.)

	Reconstructability (cont.)																	Deconstructability												
	Project Stage						Effectiveness Measures												Mechanism						Project Stage					
Survey Number	PLAN	PRE	DES	CON	O&M	DEMO	NONE	PRE$	PRESTF	CON$	CONSTF	CO	RFI	SCHED	DES	OWN	OTH	Rank	VE	CON	PLAN	MEET	MAN	OTH	PLAN	PRE	DES	CON	O&M	DEMO
1																														
2																														
3	x		x					x	x				x			x														
4																														
5															x															
6																														
7																														
8																														
9	x		x					x	x						x	x														
10																														
11			x			x	x											6	x	x		x					x			x
12																														
13																														
14										x								3						x						
15																														
16																														

Table B.1 Constructor Responses (cont.)

Survey Number	Deconstructability (cont.)																	Responsibilities													
	Effectiveness Measures											Importance						Designability							Constructability						
	NONE	PRE$	PRESTF	CON$	CONSTF	CO	RFI	SCHED	DES	OWN	OTH	Designability	Constructability	Maintainability	Operability	Reconstruct.	Deconstruct.	Owner	Designer	Constructor	CM	All	None	Other	Owner	Designer	Cosntructor	CM	All	None	Other
1												4	1	3	2	5	6		x						x	x	x	x	x		
2												4	1	2	3	5	6		x			o				x	x	x	o		
3												2	1	3	4	5	6		x	x	x					x	x	x			
4												4	1	2	3	5	6	x	x						x	x	x	x	x		
5												4	1	2	3	5	6	x	x		x					x	x	x			
6												2	1	3	4	5	6	x	x	x	x	x			x	x	x	x	x		
7												3	1	4	2	5	6	x	x	x	x	x			x	x	x	x	x		
8												3	2	4	1	5	6		x								x	x			
9												4	1	2	3	5	6	x	x	x	x	x			x	x	x	x	x		
10												1	3	4	2	5	6	x	x	x						x	x	x			
11	x											4	1	2	3	5	6		x		x	o				x	x	x	o		
12												6	3	2	1	4	5	x	x						x	x	x	x	x		
13												2	1	4	3	5			x								x	x	o		
14				x																											
15												4	1	2	3				x								x	x			
16																															

Table B.1 Constructor Responses (cont.)

Survey Number	Responsibilities (cont.)																											
	Maintainability							Operability							Reconstructability							Deconstructability						
	Owner	Designer	Cosntructor	CM	All	None	Other	Owner	Designer	Cosntructor	CM	All	None	Other	Owner	Designer	Cosntructor	CM	All	None	Other	Owner	Designer	Cosntructor	CM	All	None	Other
1	x	x						x	x						x	x						x	x					
2	x	x	x	x	x			x	x	x	x	x			x	x	x	x	x			x	x	x	x	x		
3	x	x	x	x	x			x	x	x	x	x			x	x	x	x	x			x	x					
4	x	x	x	x	x			x	x	x	x	x			x	x	x	x	x			x		x	x			
5	x	x		x				x	x		x				x	x	x	x	x					x				
6						x							x							x							x	
7	x	x	x	x	x			x	x	x	x	x			x	x		x				x	x		x			
8		x	x						x											x							x	
9	x	x	x	x	x			x	x	x	x	x			x	x	x	x	x			x	x	x	x	x		
10	x	x						x							x	x												
11	x	x	x	x	x			x	x	x	x	x				x	x		o				x	x		o		
12	x							x								x	x						x	x				
13	x							x												x							x	
14																												
15	x							x								x							x					
16																												

Table B.2 Designer Responses

Survey Number	Title	years exp. Industry	years exp. Designer	Annual Billings	Types of Facilities Designed	Design Services	% Public	% Private	% New	% Renov/	% M/R	% Decon	Designability Rank	Mechanism VE	Mechanism CON	Mechanism PLAN	Mechanism MEET	Mechanism MAN	Mechanism OTH
1	President		44	1	7,12	3	95	5	50	50			1	X			X	X	
2	principal		30	1	3,5,6,7,8,9,10	2,3,9	50	50	70	30			2		X	X	X		X
3	VP/Regional manager		20	5	1,3,8	1,2,3,6,7,8,11	50	50					2	X	X	X	X	X	X
4	Chairman/CEO		35	4	3,5,7,8,11	2,3,9,12	80	20	70	20	10								
5	Vice President		21	2	1,5,6,7,8,10,11	2,3	60	40	70	25	5		2	X		X	X	X	
6	Principal Engineer		20	1	3,7,8	2,4	40	60	95	4	1	0	2			X			
7	Transportation Design manager	4	8	2	7,8,12	2,9	90	10	50	50			2	X	X	X	X	X	
8	Consulting Engineer	13	13	1	3,8	2	50	50	100				2				X		
9	President	35	35	1	5,9,10	1,2,3,5,9	0	100	100				2			X	X		
10	Asst. Director-Operations		20	5	7,8,11	2,3,9	75	25	95	5			3	X		X	X	X	
11	President	38	38	1	1,2,3,5,6	6,7,8,11,12	80	20	60	35	3	2	3			X	X		
12	Regional Manager/VP	30	35	2	3,7	2,3,9	90	10	95	5			4			X	X		
13	President	30	30	3	3,7,8,12	1,2,3,6,7,11	100	0	90	5	5		4	X					X
14	Regional Manager/VP	8	16	3	1,3,5,7,8,9,10	2,3,6,9	70	30	35	40	20	5	4					X	
15	Transportation Engineer	1	11	1	7	9	35	65	80	20			4			X	X		X
16	VP		20	1	1,2,3,4,5,6,11	6,7,11	50	50	50	50			4			X	X	X	
17	President/Principal Engineer		10	1	3,7,8,9,10	2,9	0	100	90	5	5		4		X	X	X	X	
18	President/Principal Engineer	25	15	1	1,2,5,6,10	12	50	50	25	50	25		5		X	X	X		
19	Principal Engineer	25	20	1	8	2	90	10	90	10									
20	Owner/Project Manager	0	23	1	5,6,12	7	50	50	60	40									
21	Project Manager/Principal		20	1	9	2,5	80	20	70	30									
22	Principal	28	28	6	1,7,8,12	2,3,4	30	70	70	0	20	10							
23	Principal	28	41	1	12	6,7	90	10	65	35									
24	Principal	29	29	2	1,2,3,5,6	6,7,8,10,11	80	20	35	60	4	1							
25		25	23	1	3,7,8	2,8,9	85	15	30	70									

Table B.2 Designer Responses (cont.)

	Designability (cont.)																	Constructability												
	Project Stage						Effectiveness Measures												Mechanism						Project Stage					
Survey Number	PLAN	PRE	DES	CON	O&M	DEMO	NONE	DES$	DESSTF	CON$	CONSP$	CONSTF	CO	RFI	CONFD	OWN	OTH	Rank	VE	CON	PLAN	MEET	MAN	OTH	PLAN	PRE	DES	CON	O&M	DEMO
1	x	x	x					x	x	x			x	x	x	x		2	x	x	x	x			x	x	x	x		
2	x	x						x					x					1		x	x			x			x			
3	x	x	x							x			x	x				1	x	x	x	x			x	x	x	x	x	x
4																														
5		x						x										1	x	x	x	x	x			x				
6	x						x											1				x					x			
7	x	x	x		x	x		x	x	x			x	x	x			1	x	x	x	x			x	x	x			
8	x								x							x		1	x	x	x	x				x				
9		x					x											1			x	x				x				
10			x				x											1	x	x	x		x				x			
11	x	x	x					x	x	x						x		2	x	x	x						x			
12	x	x						x	x									3		x	x					x	x			
13	x	x	x		x					x			x			x	x	2	x	x				x	x	x	x		x	
14	x	x					x											1	x	x	x	x	x				x	x		
15	x	x	x	x				x	x									3		x	x	x		x	x	x	x			
16	x	x	x					x										3	x	x	x	x	x		x	x	x			
17	x	x						x						x	x	x		3	x	x	x	x	x		x	x				
18		x	x											x		x		2	x	x	x	x			x	x	x	x		x
19																		3			x	x					x			
20																														
21																		1	x	x	x	x				x	x			
22																		1	x	x	x	x			x	x	x			
23																		2		x	x	x			x	x	x	x		
24																		3	x	x	x	x				x	x	x		x
25																		3			x	x					x			

Table B.2 Designer Responses (cont.)

	Constructability (cont.)											Maintainability																							
	Effectiveness Measures												Mechanism						Project Stage						Effectiveness Measures										
Survey Number	NONE	DES$	DESSTF	CON$	CONSP$	CONSTF	CO	RFI	CONFD	OWN	OTH	Rank	VE	CON	PLAN	MEET	MAN	OTH	PLAN	PRE	DES	CON	O&M	DEMO	NONE	DES$	DESSTF	CON$	CONSP$	CONSTF	CO	RFI	CONFD	OWN	OTH
1			x	x	x	x	x	x	x	x		3			x				x	x	x	x						x						x	
2				x			x	x				4			x			x			x													x	
3				x			x	x	x			3	x	x		x			x	x	x	x	x	x										x	
4																																			
5				x																															
6	x											3						x			x				x										
7				x	x	x	x	x	x	x		3	x	x	x	x				x	x	x			x									x	
8				x				x	x	x		4			x	x					x						x							x	
9	x																																		
10	x																																		
11				x	x	x	x	x	x	x		4	x								x				x										
12				x			x	x	x		x	2						x		x	x													x	x
13				x			x	x	x	x		3						x			x	x	x										x	x	x
14	x											3	x	x	x								x		x										
15				x			x		x	x		2		x	x	x		x	x	x	x												x	x	
16				x	x	x	x	x	x			2	x		x	x	x		x	x	x													x	
17				x				x	x	x		1	x							x	x	x	x											x	
18							x	x	x			1		x	x	x			x	x	x	x									x			x	
19				x			x			x		2			x	x					x													x	
20																																			
21									x			2	x		x	x				x	x													x	
22						x			x	x		3			x	x					x	x												x	
23	x																																		
24									x			2			x	x				x	x	x	x											x	
25				x								2			x	x			x	x	x	x	x											x	

Table B.2 Designer Responses (cont.)

	Operability																								Reconstructability						
		Mechanism						Project Stage						Effectiveness Measures												Mechanism					
Survey Number	Rank	VE	CON	PLAN	MEET	MAN	OTH	PLAN	PRE	DES	CON	O&M	DEMO	NONE	DES$	DESSTF	CON$	CONSP$	CONSTF	CO	RFI	CONFD	OWN	OTH	Rank	VE	CON	PLAN	MEET	MAN	OTH
1	4							x	x	x	x	x											x								
2	3			x		x		x															x								
3	4	x	x		x			x	x	x	x	x	x										x								
4																															
5																									3	x					
6																															
7																															
8	3			x	x					x						x							x		6				x		
9																															
10	2	x								x				x																	
11	1			x	x	x		x	x								x					x	x								
12	1						x		x	x													x	x	5						x
13	1						x	x			x											x	x								
14	2	x	x	x								x		x																	
15	1			x	x		x	x	x	x												x	x		5			x	x		x
16	1	x		x	x	x		x	x	x													x								
17	2	x							x	x	x	x											x								
18	3		x	x	x			x	x	x	x	x											x		4			x	x		
19	1			x	x				x	x													x		4			x	x		
20																															
21	3	x		x	x				x	x													x								
22	2			x	x				x	x													x		4			x	x		
23	1		x	x	x			x	x	x	x			x																	
24	1			x	x			x	x	x		x											x		4			x	x		
25	1			x	x			x	x	x	x	x											x								

Table B.2 Designer Responses (cont.)

	Reconstructability (cont.)																	Deconstructability												
	Project Stage						Effectiveness Measures												Mechanism						Project Stage					
Survey Number	PLAN	PRE	DES	CON	O&M	DEMO	NONE	DES$	DESSTF	CON$	CONSP$	CONSTF	CO	RFI	CONFD	OWN	OTH	Rank	VE	CON	PLAN	MEET	MAN	OTH	PLAN	PRE	DES	CON	O&M	DEMO
1																														
2																														
3																														
4																														
5			x				x																							
6																														
7																														
8			x						x							x		5				x					x			
9																														
10																														
11																														
12		x	x													x	x													
13																														
14																														
15	x	x	x												x	x														
16																														
17																														
18																														
19	x	x	x				x																							
20																														
21																														
22		x	x													x														
23																														
24	x	x	x	x											x	x														
25																														

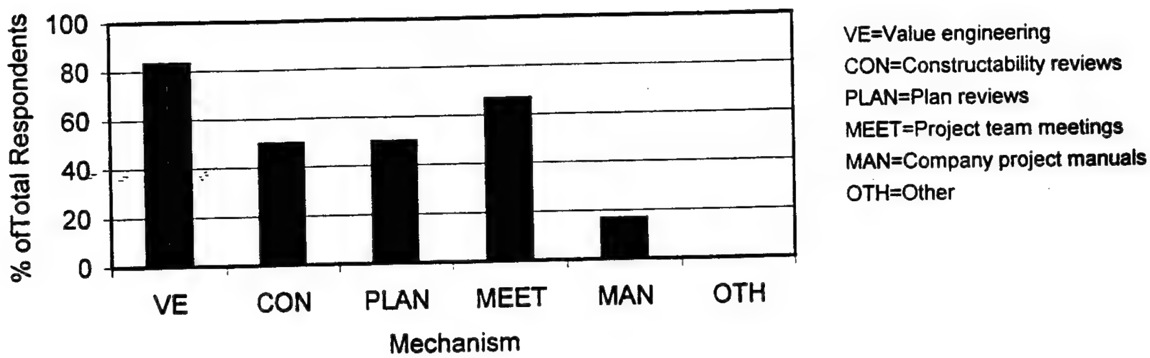
Table B.2 Designer Responses (cont.)

	Deconstructability (cont.)																	Responsibilities													
	Effectiveness Measures											Importance						Designability							Constructability						
Survey Number	NONE	DES$	DESSTF	CON$	CONSP$	CONSTF	CO	RFI	CONFD	OWN	OTH	Designability	Constructability	Maintainability	Operability	Reconstruct.	Deconstruct.	Owner	Designer	Const.	CM	All	None	Other	Owner	Designer	Const.	CM	All	None	Other
1												4	3	2	1			x	x	x	x	x			x	x	x	x	x		
2												4	2	3	1				x							x	x	x			
3												4	1	2	3			x	x	x	x	x			x	x	x	x	x		
4												1	2	4	3				x			o				x	x		o		
5												2	1	5	4	3	6		x						x	x	x	x	x		
6												4	3	2	1	5	6		x							x					
7												4	3	2	1	5	6		x			o			x	x	x	x	x		
8			x									4	1	3	2	6	5	x	x							x	x	x			
9												2	1	3	4	5	6	x	x	x	x	x			x	x	x	x	x		
10																															
11												2	1	5	4	3	6	x	x						x	x	x	x	x		
12												4	3	2	1	5		x	x						x	x	x				
13												4	3	2	1				x	x	x	o				x	x	x	o		
14												4	1	3	2			x	x							x	x	x			
15												6	4	2	1	3	5	x	x							x	x	x			
16												4	3	2	1	5	6	x	x						x	x	x	x	x		
17												6	1	4	3	2	5		x			o			x	x	x	x	x		
18												4	2	1	3	5	6		x							x	x				
19													3	2	1	4			x							x	x	x			
20												5	3	1	2	4	6	x	x							x	x				
21												4	1	2	3	5	6	x	x						x	x	x	x	x		
22												4	1	3	2	5	6		x						x	x	x	x	x		
23																															
24												5	3	2	1	4	6	x							x	x	x	x	x		
25												5	3	2	1	4	6		x		x					x		x			

Table B.2 Designer Responses (cont.)

	Responsibilities (cont.) Maintainability							Operability							Reconstructability							Deconstructability						
Survey Number	Owner	Designer	Const.	CM	All	None	Other	Owner	Designer	Const.	CM	All	None	Other	Owner	Designer	Const.	CM	All	None	Other	Owner	Designer	Const.	CM	All	None	Other
1	x	x	x	x	x			x	x	x	x	x								x							x	
2	x							x	x	x										x							x	
3	x	x	x	x	x			x	x	x	x	x								x							x	
4	x				o			x				o								x							x	
5	x							x							x	x												
6	x							x								x						x						
7	x	x	x	x	x			x		x	x	o			x				o			x				o		
8	x	x						x	x							x	x	x					x	x	x			
9	x	x	x	x	x			x	x	x	x	x								x							x	
10																												
11	x	x	x	x	x			x	x	x	x	x			x	x	x	x	x			x	x	x	x	x		
12	x	x						x	x						x	x											x	
13	x	x	x		o			x	x			o			x	x	x		o			x						
14	x	x						x	x		x				x	x						x	x					
15	x	x	x	x	x			x	x	x	x	x			x	x	x	x	x								x	
16	x	x	x	x	x			x	x	x	x	x			x	x	x	x	x			x						
17	x	x	x	x	x			x	x	x	x	x				x	x	x	o				x	x	x	o		
18	x	x	x	x	x			x	x	x	x	x			x	x						x	x					
19	x	x						x	x							x							x					
20	x	x						x	x	x					x	x						x	x					
21	x	x						x	x						x	x	x	x	x			x	x	x	x	x		
22	x	x						x	x		x				x	x						x	x					
23																												
24	x	x	x	x	x			x	x	x	x	x			x	x	x	x	x								x	
25	x	x		x				x	x		x				x	x		x									x	

Appendix C Constructor and Designer Current Practices



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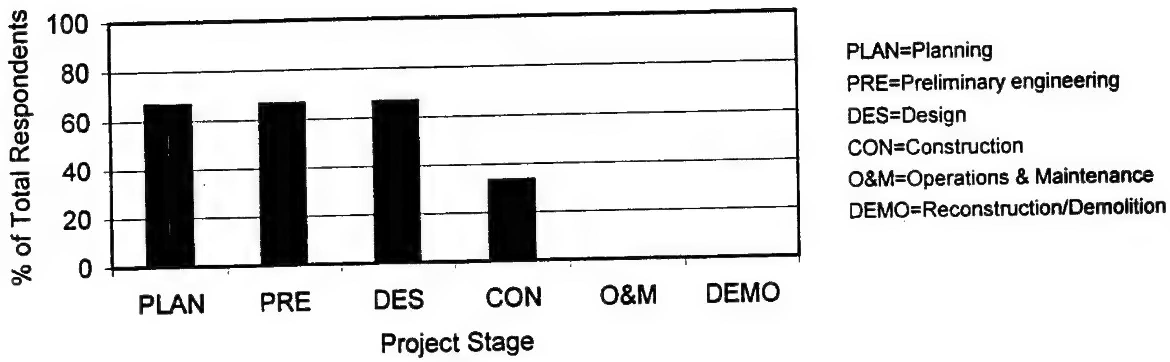

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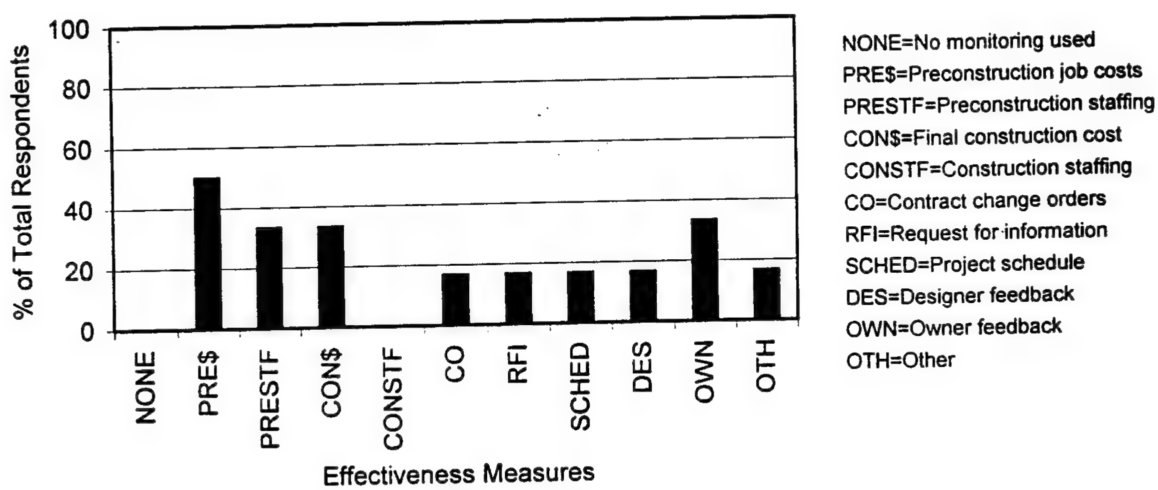


(c)

Figure C.1 Designability - Constructors Responses
(a) Practices by which life cycle properties are formally addressed;
(b) The stage of a project in which life cycle properties are formally addressed;
(c) The measures used to determine effectiveness of addressing life cycle properties.

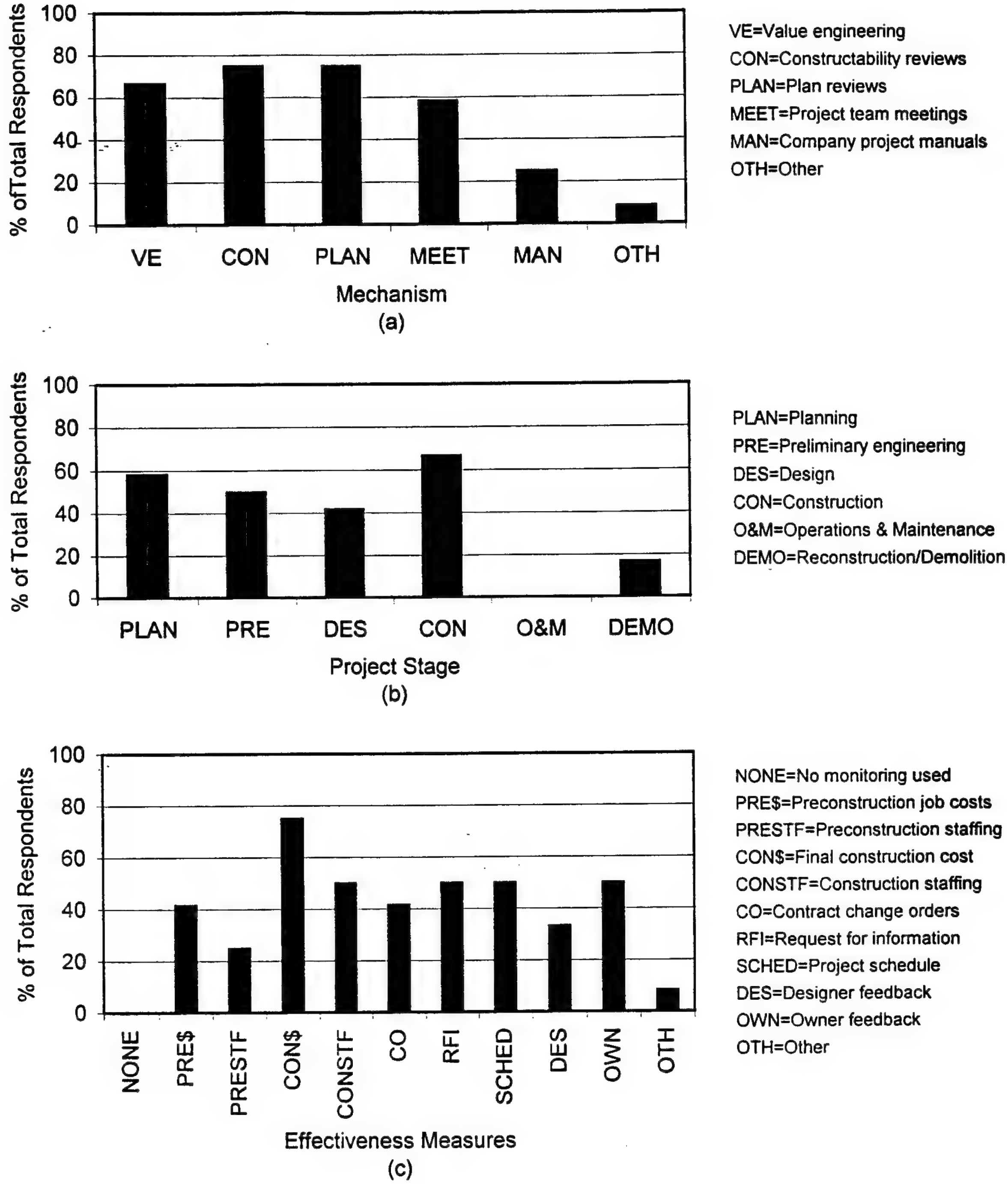


Figure C.2 Constructability - Constructors Responses

(a) Practices by which life cycle properties are formally addressed;
(b) The stage of a project in which life cycle properties are formally addressed;
(c) The measures used to determine effectiveness of addressing life cycle properties.

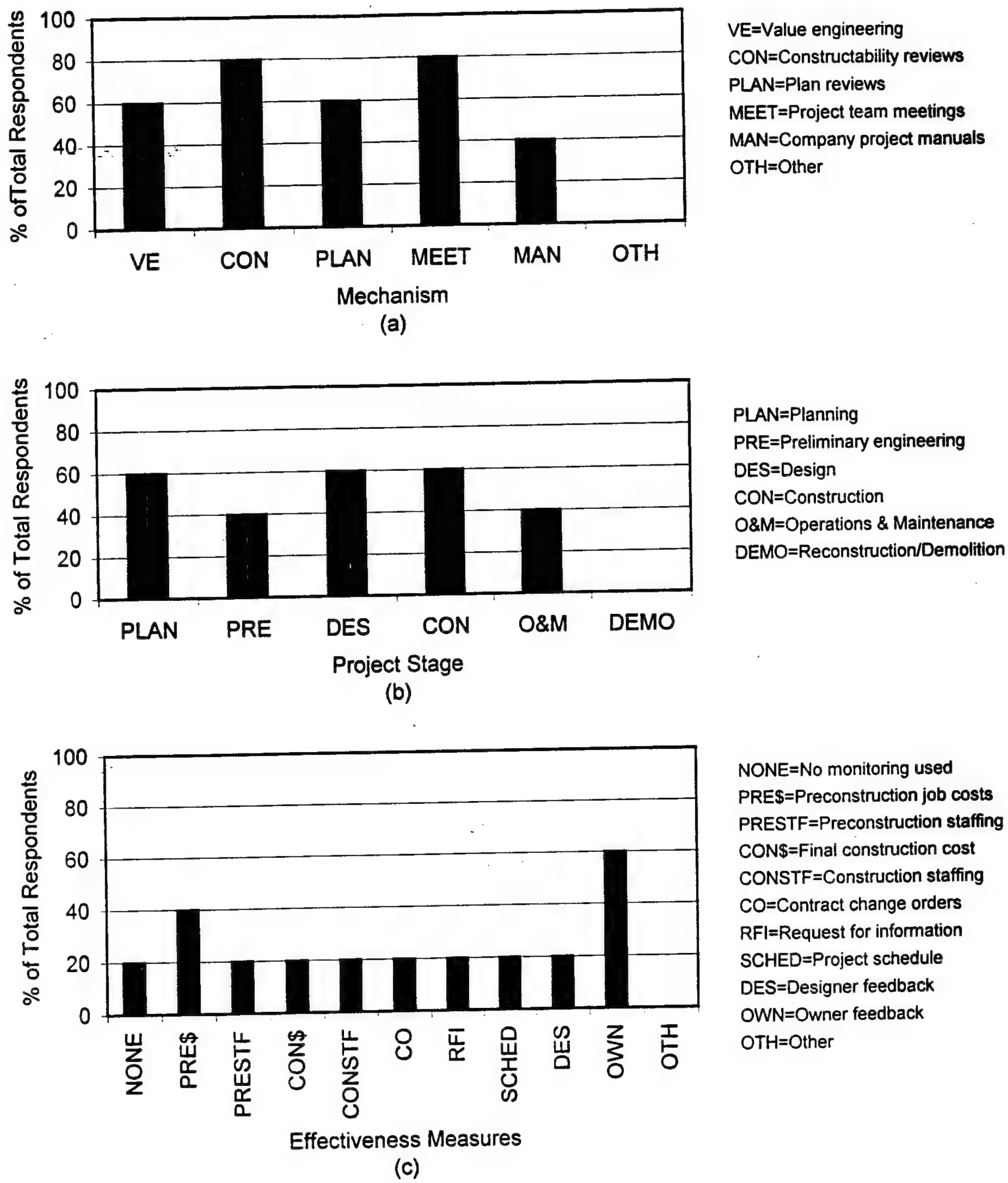


Figure C.3 Maintainability - Constructors Responses
(a) Practices by which life cycle properties are formally addressed;
(b) The stage of a project in which life cycle properties are formally addressed;
(c) The measures used to determine effectiveness of addressing life cycle properties.

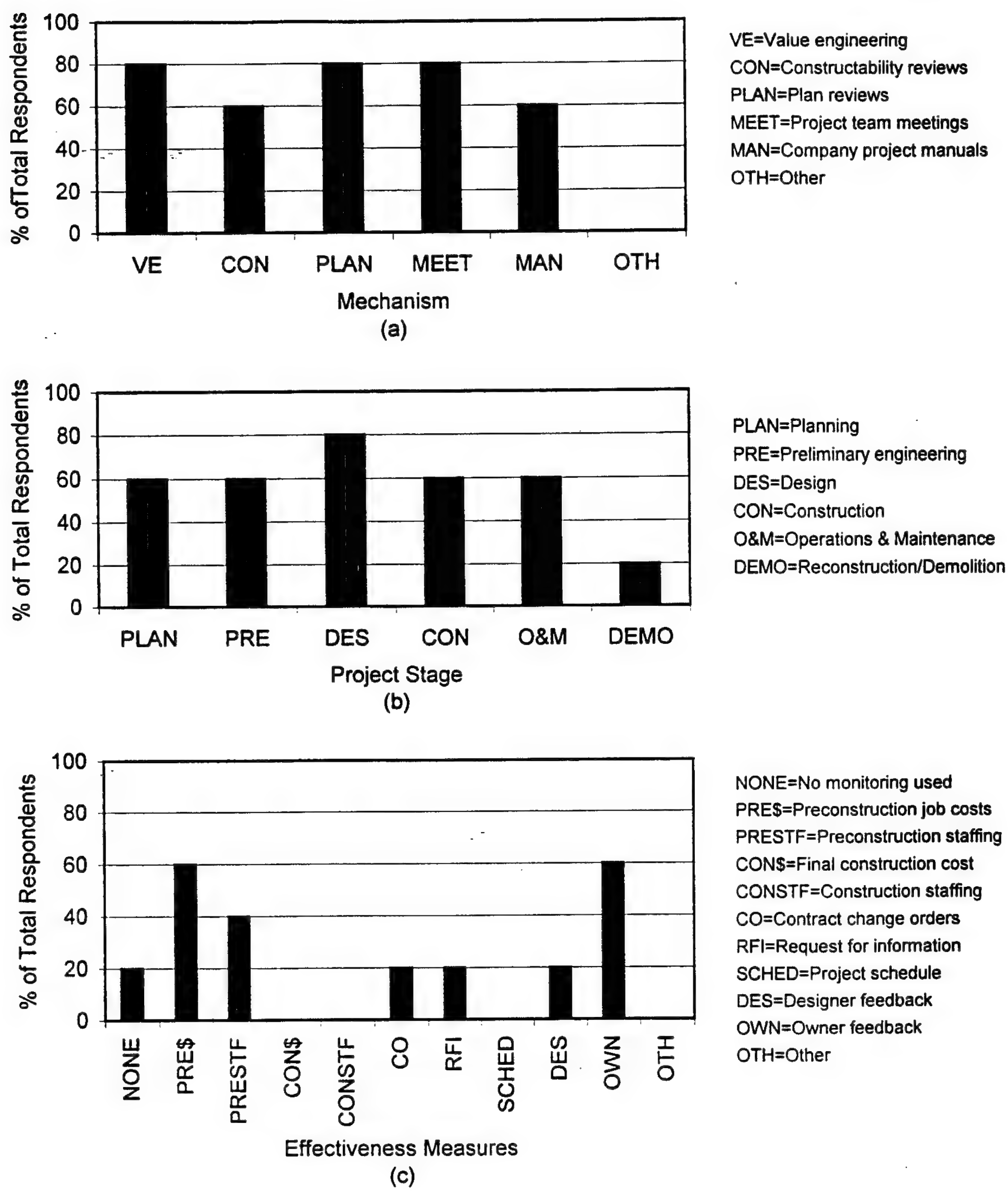


Figure C.4 Operability - Constructors Responses

(a) Practices by which life cycle properties are formally addressed;
(b) The stage of a project in which life cycle properties are formally addressed;
(c) The measures used to determine effectiveness of addressing life cycle properties.

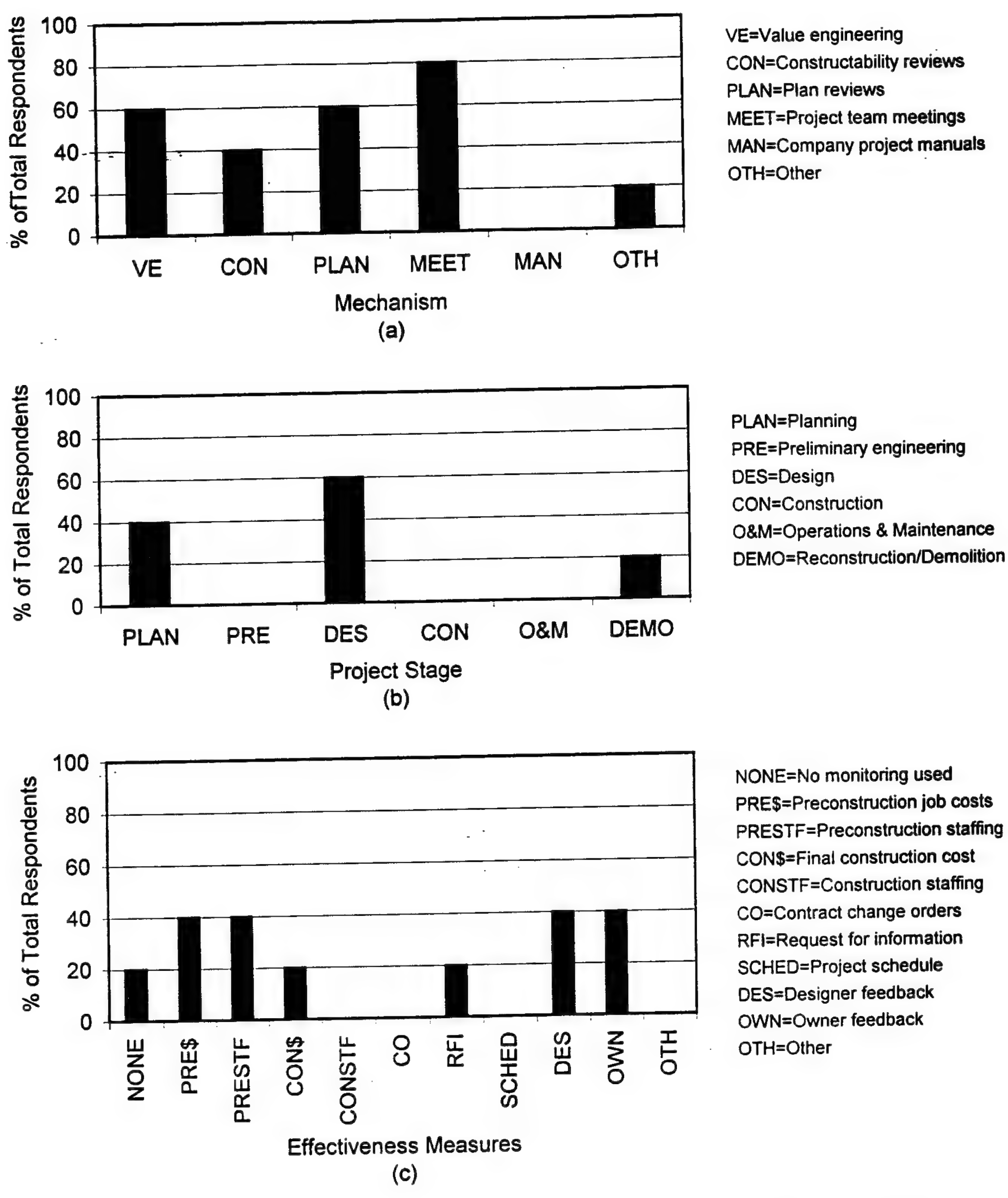
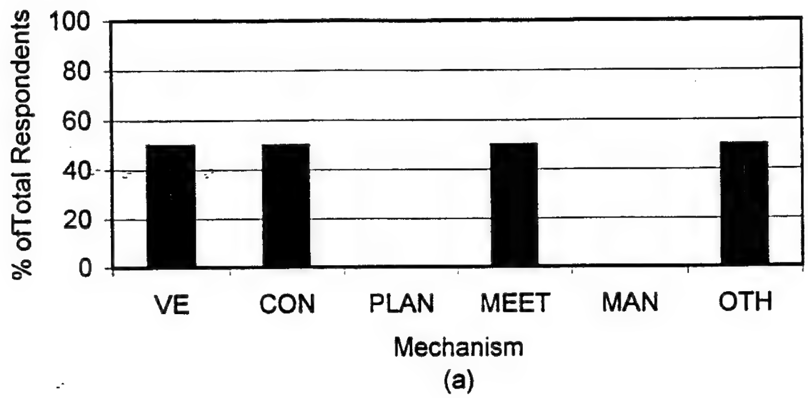
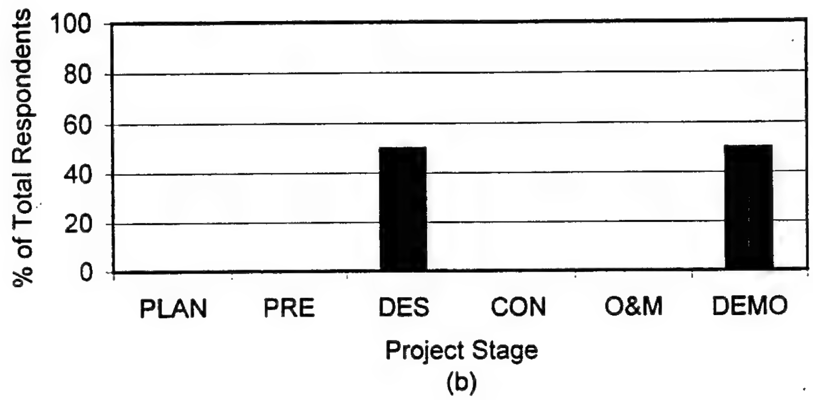


Figure C.5 Reconstructability - Constructors Responses

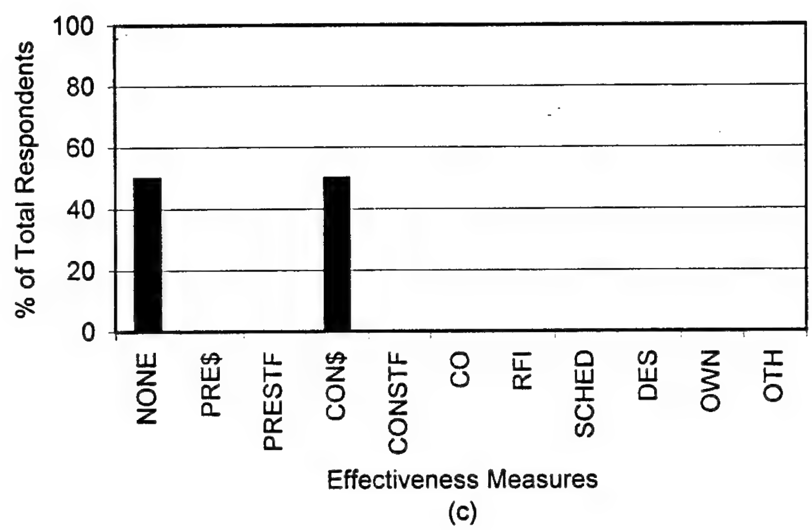
(a) Practices by which life cycle properties are formally addressed;
(b) The stage of a project in which life cycle properties are formally addressed;
(c) The measures used to determine effectiveness of addressing life cycle properties.



VE=Value engineering
CON=Constructability reviews
PLAN=Plan reviews
MEET=Project team meetings
MAN=Company project manuals
OTH=Other

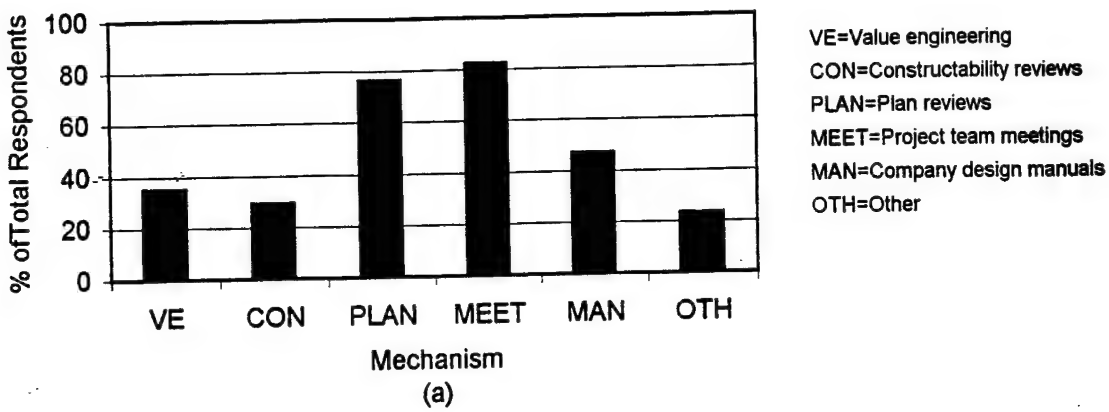


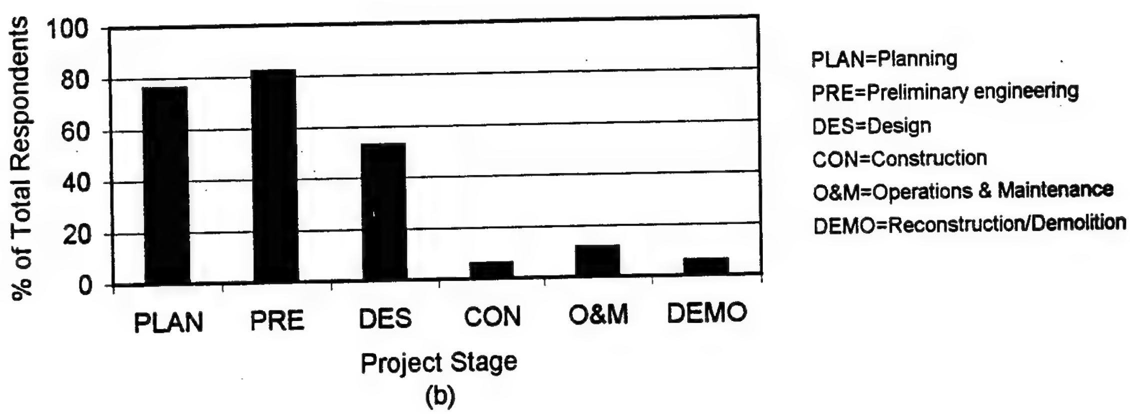
PLAN=Planning
PRE=Preliminary engineering
DES=Design
CON=Construction
O&M=Operations & Maintenance
DEMO=Reconstruction/Demolition



NONE=No monitoring used
PRE$=Preconstruction job costs
PRESTF=Preconstruction staffing
CON$=Final construction cost
CONSTF=Construction staffing
CO=Contract change orders
RFI=Request for information
SCHED=Project schedule
DES=Designer feedback
OWN=Owner feedback
OTH=Other

Figure C.6 Deconstructability - Constructors Responses
(a) Practices by which life cycle properties are formally addressed;
(b) The stage of a project in which life cycle properties are formally addressed;
(c) The measures used to determine effectiveness of addressing life cycle properties.





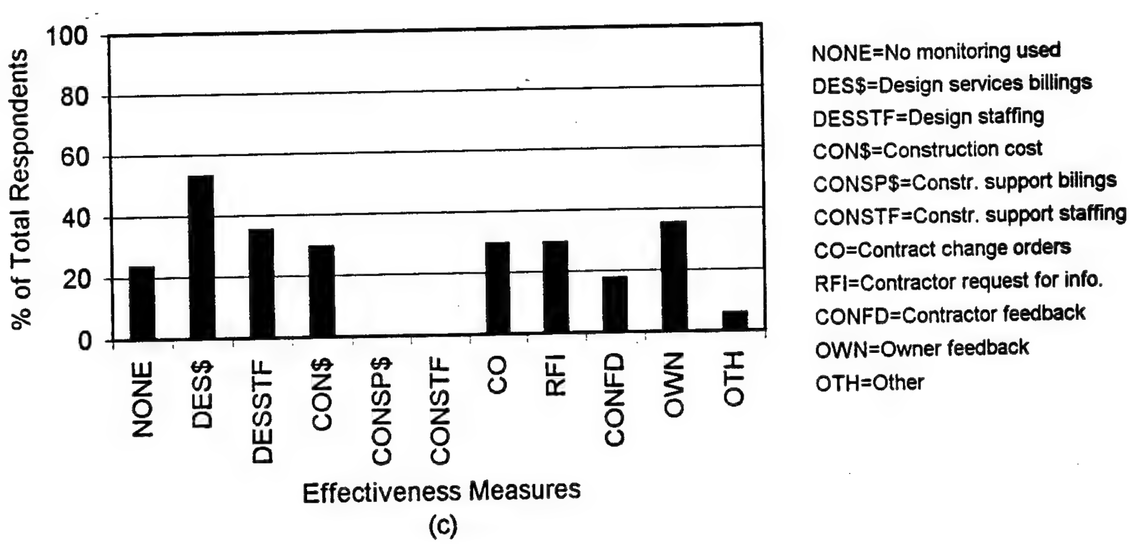
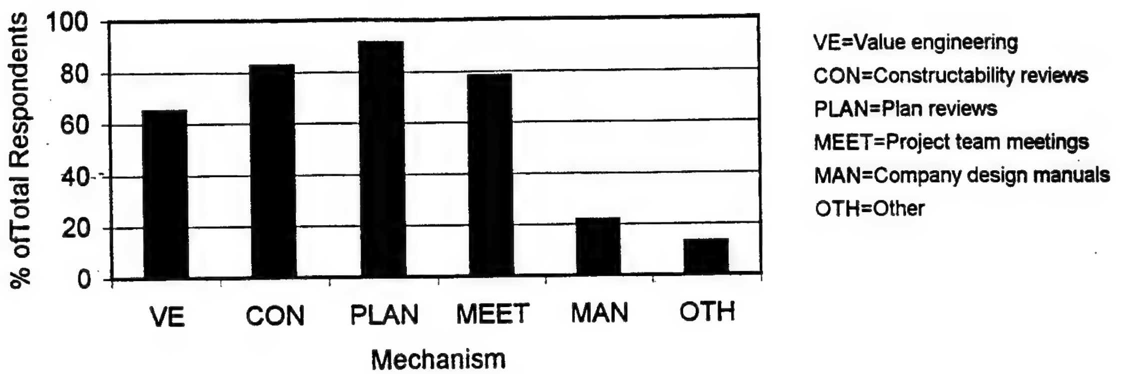


Figure C.7 Designability - Designers Responses

(a) Practices by which life cycle properties are formally addressed;

(b) The stage of a project in which life cycle properties are formally addressed;

(c) The measures used to determine effectiveness of addressing life cycle properties.



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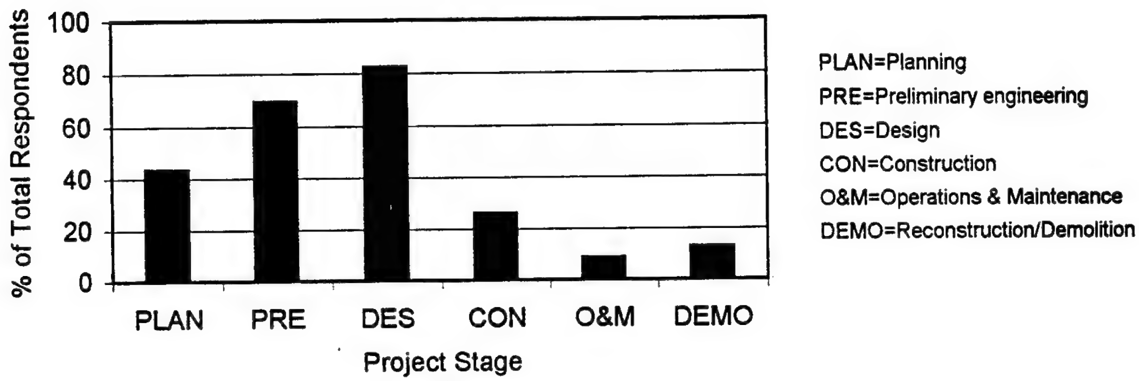

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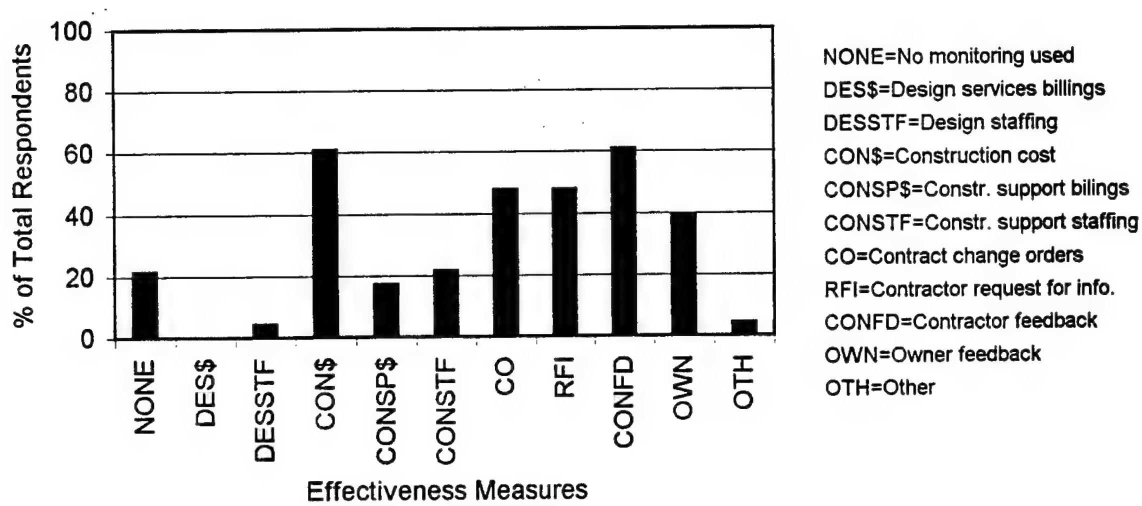


(c)

Figure C.8 Constructability - Designers Responses

(a) Practices by which life cycle properties are formally addressed;
(b) The stage of a project in which life cycle properties are formally addressed;
(c) The measures used to determine effectiveness of addressing life cycle properties.

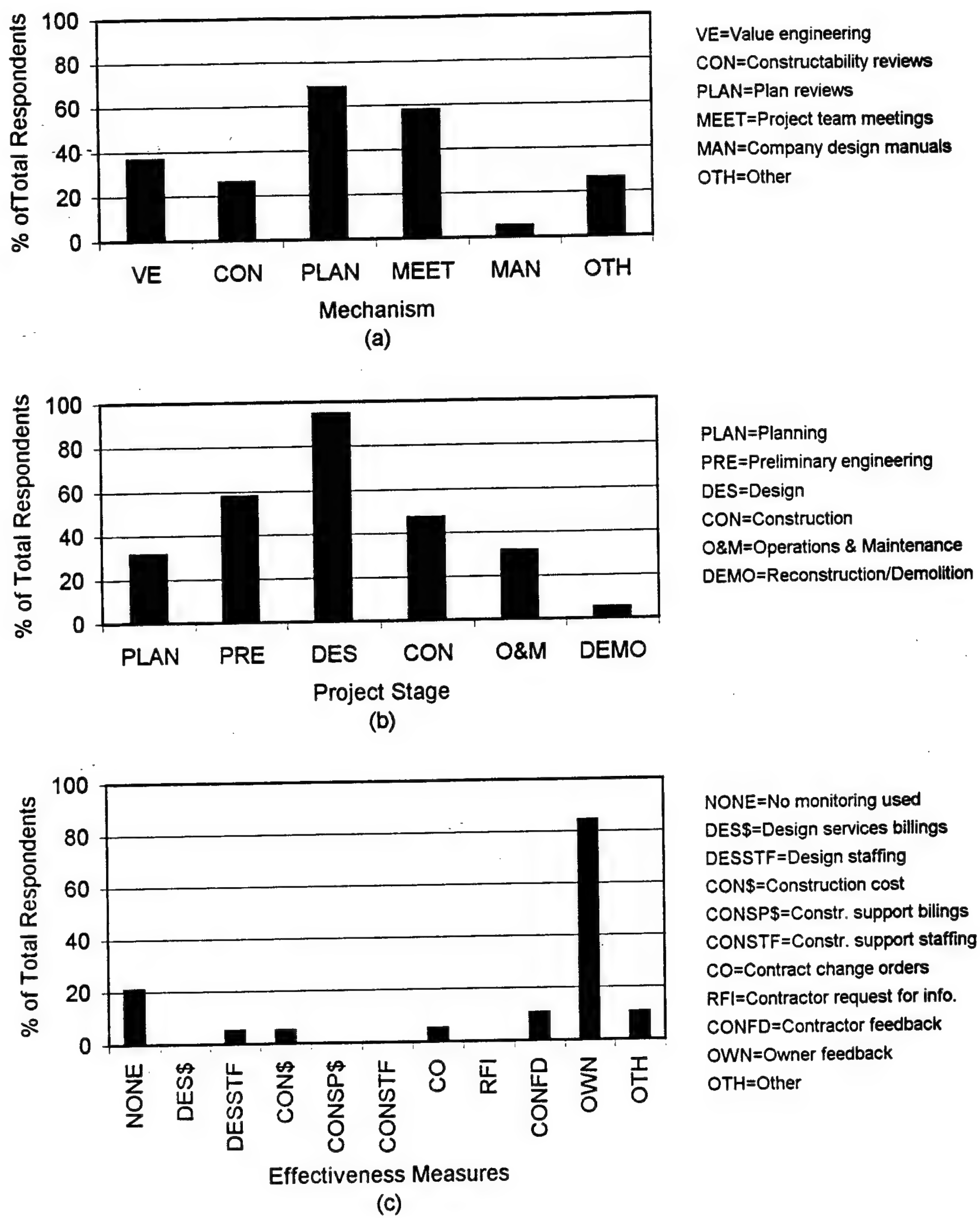
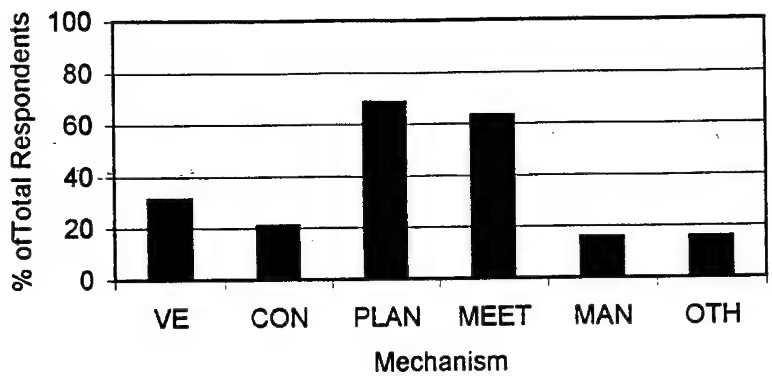


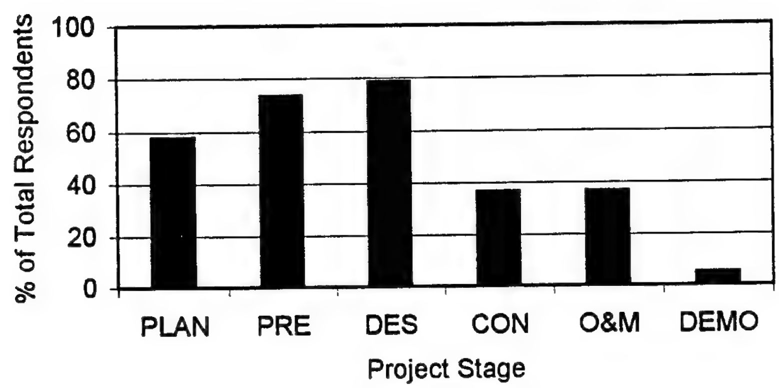
Figure C.9 Maintainability - Designers Responses

(a) Practices by which life cycle properties are formally addressed;
(b) The stage of a project in which life cycle properties are formally addressed;
(c) The measures used to determine effectiveness of addressing life cycle properties.



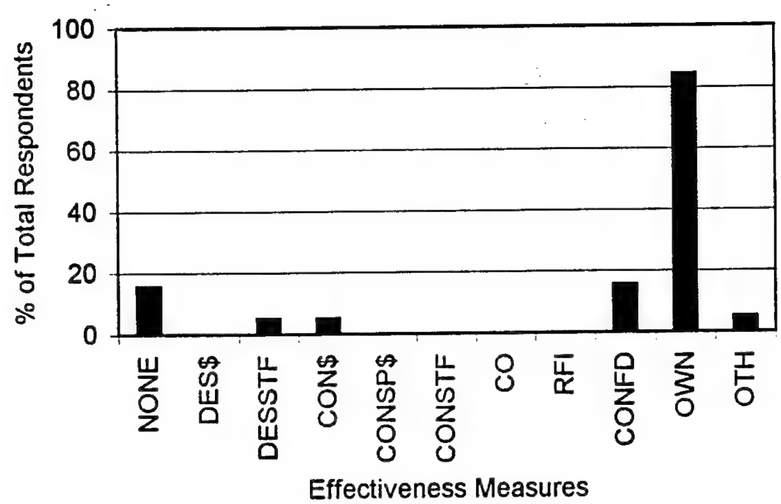
(a)

VE=Value engineering
CON=Constructability reviews
PLAN=Plan reviews
MEET=Project team meetings
MAN=Company design manuals
OTH=Other



(b)

PLAN=Planning
PRE=Preliminary engineering
DES=Design
CON=Construction
O&M=Operations & Maintenance
DEMO=Reconstruction/Demolition



(c)

NONE=No monitoring used
DES$=Design services billings
DESSTF=Design staffing
CON$=Construction cost
CONSP$=Constr. support bilings
CONSTF=Constr. support staffing
CO=Contract change orders
RFI=Contractor request for info.
CONFD=Contractor feedback
OWN=Owner feedback
OTH=Other

Figure C.10 Operability - Designers Responses

(a) Practices by which life cycle properties are formally addressed;
(b) The stage of a project in which life cycle properties are formally addressed;
(c) The measures used to determine effectiveness of addressing life cycle properties.

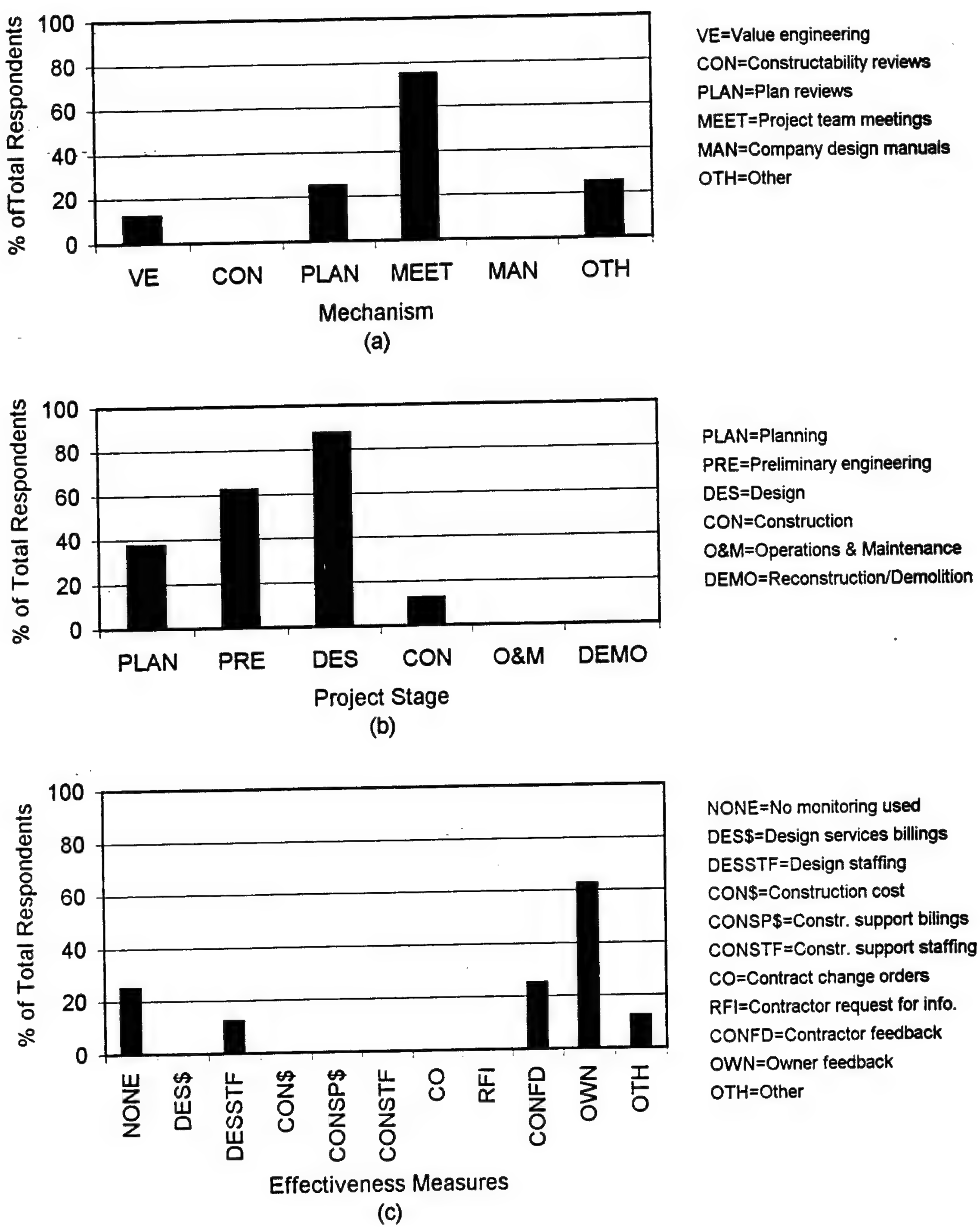


Figure C.11 Reconstructability - Designers Responses

(a) Practices by which life cycle properties are formally addressed;
(b) The stage of a project in which life cycle properties are formally addressed;
(c) The measures used to determine effectiveness of addressing life cycle properties.

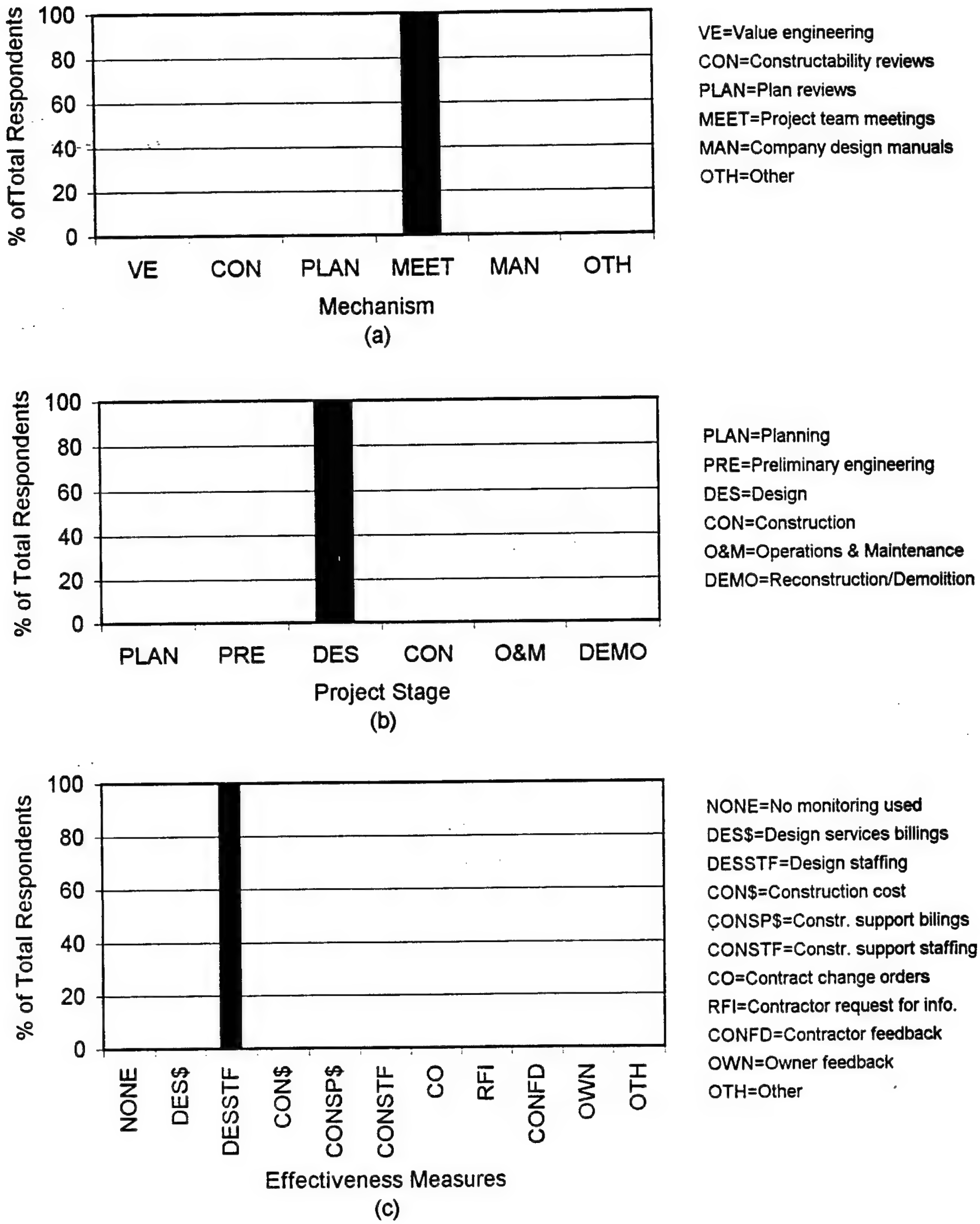
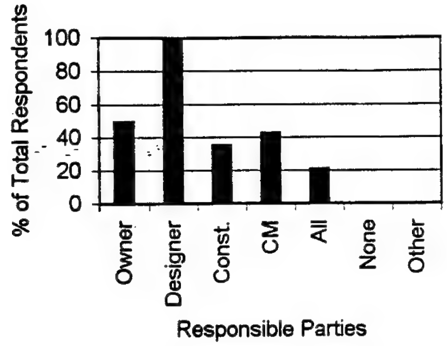


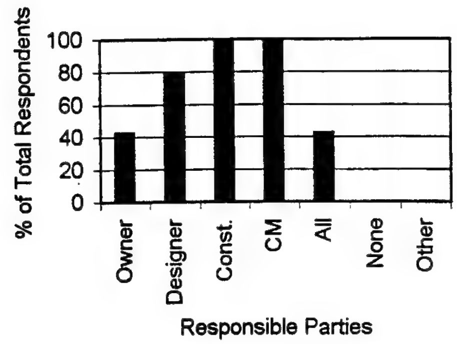
Figure C.12 Deconstructability - Designers Responses

(a) Practices by which life cycle properties are formally addressed;
(b) The stage of a project in which life cycle properties are formally addressed;
(c) The measures used to determine effectiveness of addressing life cycle properties.

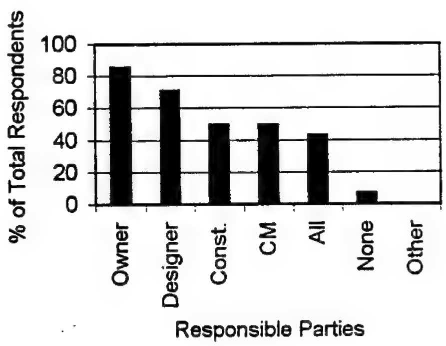
Appendix D Life Cycle Property Responsibilities



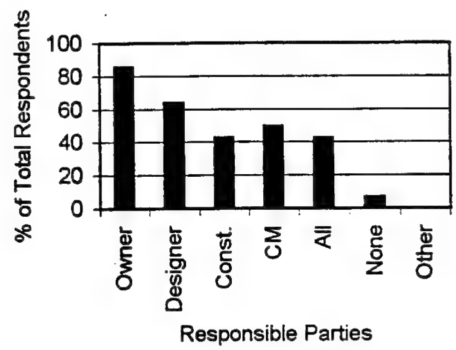
(a) Designability



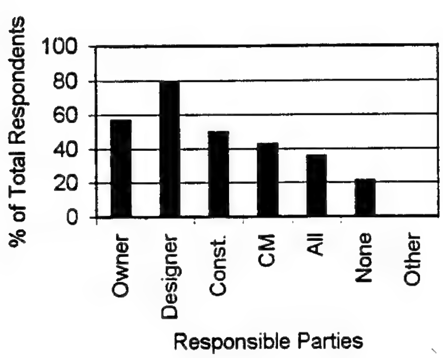
(b) Constructability



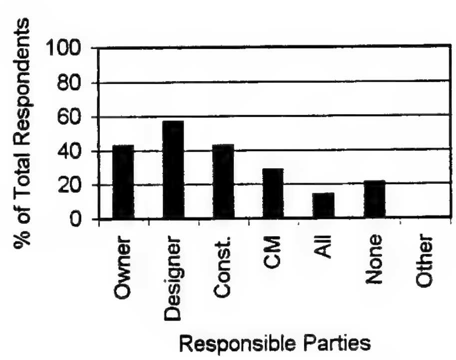
(c) Maintainability



(d) Operability

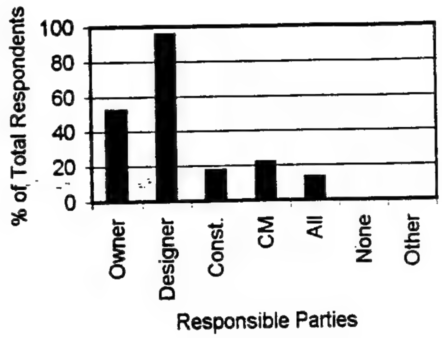


(e) Reconstructability

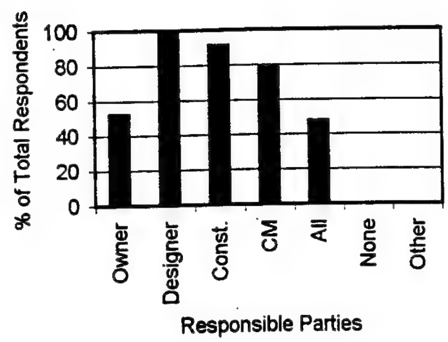


(f) Deconstructability

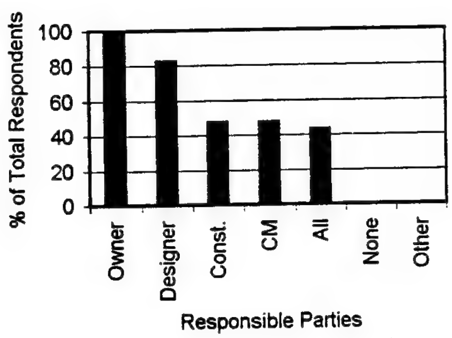
Figure D.1 Responsibilities - Constructor Responses



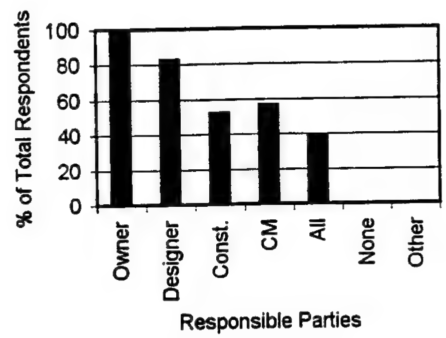
(a) Designability



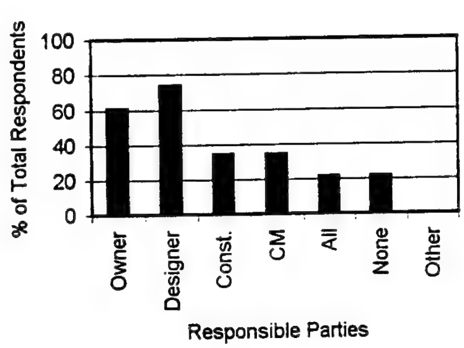
(b) Constructability



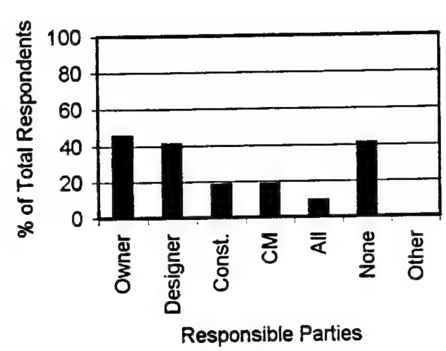
(c) Maintainability



(d) Operability



(e) Reconstructability



(f) Deconstructability

Figure D.2 Responsibilities - Designer Responses

Appendix E Constructor and Designer Comments

Constructors:

Definitions of life cycle properties:

Designability: Add: and achieves the owner's goals.

What trends relating to specific life cycle properties may impact your firm in the next 5 to 10 years?

- Tracking prior project success and other projects to increase value to owner of construction service at pre-construction period.
- Continued trend of over valuing first cost as compared to life cycle cost, i.e. low first cost usually wins.
- Energy sensitive materials/assemblies increasing cost and decreasing in availability.
- Designers relying more on builders to sort out these issues, rather than truly evaluating these matters during design process.
- Reducing labor content.
- Standardized designs used more.
- Failure by owners to recognize and plan for replacement of facilities prior to the end of their useful life is causing a shift in emphasis from new construction to rehab and replacement.
- Recycling of building material and components.
- Energy costs.
- Flexibility of building for unknown future uses.
- Risks of new products, components.
- Constructability - A strong trend toward faster, more efficient and cost effective construction as owners (particularly in the hi-tech sector) need facilities immediately.
- Maintainability, Operability - Owners are demanding more flexibility and efficiency in their facility.

Specific examples or methods of how life cycle properties have been addressed on past projects:

Designability:

- Company published material or system "watch" warning/reports.
- Promoted repetitive, simple structural systems.
- Work with the designer to enhance design and plans.
- Bidder design.
- Work with architects informally to develop details and designs.

Constructability:

- Past project history/lessons learned
- Staff team assigned to study documents in specific timeframes and forum addressing these matters.
- Continual review of design documents for coordination during all phases of design.
- Promoted design and construction techniques that improve overall constructability.
- Value engineering suggestions.
- Best value.
- Complete analysis on every project completed by both office and field personnel. Formal review and documentation with the project team.

Maintainability:

- Recommendations to owner.
- Ease.
- M.E.P. systems review with owner and design team.

Operability:

- Recommendations to owner.
- Experience to operate.

- Understand the owners operating requirements.

Reconstructability:

- Replacement or additions.
- Not considered.

Deconstructability:

- Rarely considered.

All:

- Pre-construction and design meetings to understand what the owner "thinks" his goals of the project are and than test that through both value added items and ideas and value engineering. Very important on long term owner occupied building verses the other end of the spectrum being a spec. developer who sells the project in a year or two.

Designers:

Definitions of life cycle properties:

Designability:

- Should include clarity and completeness of contract documents.

Constructability:

- Should reflect only the ease with which project can be constructed.
- Often the client/owner refers to constructability as the ability to meet the project budget. Unfortunately lower capital cost is usually selected in spite of higher O&M (long-term) costs for most projects. "Life cycle" is usually ignored when project elements are pared to bring a project into "budget."

Reconstructability:

- Enlargeability.

What trends relating to specific life cycle properties may impact your firm in the next 5 to 10 years?

- The movement to design/build and engineer finance projects.
- In our design work most facilities are standardized by the respective operating or approving agencies. Therefore, the design exercise is more related to fitting the given pieces together so that they will perform correctly rather than creating new designs that can address life cycle issues.
- Life cycle costs are the most important factor(s) provided that the facilities perform as designed and meet regulatory performance criteria. Life cycle costs are driven by construction costs (constructability) and O&M costs (operability and maintainability).
- Maintainability and operability will become more important.
- Operability and maintainability are greatly impacted by the electrical controls and SCADA systems and interfacing the password controls and programs into the design to include response time will be a challenge.
- Environmental issues which need to be addressed at the construction site will impact constructability.
- Reconstructability is always a concern due to the lack of complete as-constructed plans and thereby pose a greater risk from a liability standpoint and risk management.
- Design-build practice.
- Use of "standard" design.
- Increased awareness on part of owners to address operability and maintainability in more detail in order to control long term costs.
- Public works project managers are trying to obtain more design services at lower costs which result in fewer opportunities to explore new design ideas. Life cycle evaluations are omitted; traditional materials and standard specifications are used for most designs.
- Building life cycles of less than 20 years.

- Operability and maintainability: "Sustainable" design increased interest in life cycle cost analysis (NPV/IRR) by owners.
- As existing facilities age and reach their expected life cycle, we expect to see an increasing demand for reconstruction.
- You should add "permitability." Engineering and design is easy compared to obtaining permits. Permit requirements drive projects more than cost or engineering considerations.
- Operability as related to owner's productivity.
- Sustainable design.
- Energy conservation.
- Construction costs.
- Skill of design and construction labor force.
- The design-build trend.
- Many owners do not have access to enough capital to do what they want/used to do.
- Design-build issues to minimize construction change orders and improve schedule.
- Recognition that many civil engineering features (water resource facilities, pipelines, sewers, retaining walls) have a true and useful life much longer than that normally used in life cycle cost evaluations.

Specific examples or methods of how life cycle properties have been addressed on past projects:

Designability:

- Cost estimating the project and during value engineering.
- Preliminary stages.
- Use accepted design procedures.
- Basic utility work does not leave much room for options. We generally follow prescribed procedures, esp. for storm drainage design, in accordance with requirements at local jurisdictions.

- Only a problem when there is no standard of practice.
- Mid and top management of project costs (design costs).

Constructability:

- Constructability reviews by experienced construction managers.
- Fitting an experimental storm water treatment and detention facility into a confining site, extending several design elements to their limit.
- Detailed reviews at several points in the design process by owner, operator and firm's staff having C/M experience.
- Design stage, discuss with contractors, fabricators.
- Review by experienced personnel.
- Contractor review.
- Design review with architect and contractor and owner at concept stage, DD, and CD stages.
- On design-build projects, involving construction partner in constructability reviews.
- Detailed narratives of phasing of construction on contract documents.
- Having the design staff involved in the construction phase. Recent strong effort to have "better" contract documents.

Maintainability:

- Equipment supplier and client review.
- Operations staff (in-house) review.
- If the build it, will someone maintain it? Involved in recent project following new SD design manual. State transportation maintenance people did not want to have to maintain the detention pipes. Is anyone maintaining them?
- Detailed review by owner's operations personnel, who are also responsible for maintenance. Review takes place at several stages of design process.
- Preliminary and design stage.

- The follow up on the project after one year is most important in assessing operability and maintenance.
- Keep it simple!
- Input from maintenance personnel.
- Reduced long term costs of leakage by designing coping that doesn't leak.
- Design of equipment supports to eliminate pitch pockets.
- Involve owner maintenance personnel in design process
- Incorporate appropriate guidelines in design manual.
- Showing maintenance access spaces on plans.

Operability:

- Client review.
- Operations staff (in-house) review.
- Involved in project where contractor and agency staff alter a pump station design resulting in less pump efficiency.
- Detailed review by owner's operations personnel, who are also responsible for maintenance. Review takes place at several stages of design process.
- Preliminary and design stage.
- The follow up on the project after one year is most important in assessing operability and maintenance.
- Know what you design!
- Input from maintenance personnel.
- Involve owner maintenance personnel in design process
- Incorporate appropriate guidelines in design manual.
- Detailed sequences of operation narratives.

Reconstructability:

- Equipment supplier review.
- Providing details separating roofing work from wall cladding.
- Changed internal zoning of dams to allow future enlargements.

- Complete layout of future work including physical, capacity, and other design parameters being listed.

All:

- Senior QA/QC principal review.
- The project team consists of experienced personnel who have designed similar projects. The QA/QC program at 15%, 55%, and 75% of planning and design is effective if the QA/QC team consists of experienced personnel, is multi-disciplined and also includes the client and operational and maintenance personnel. The QA/QC meeting should encourage communication and if necessary be facilitated. Dollars are always an important consideration and cost estimators should be available at all QA/QC's.
- No formalized process. Our effort consists of in-house "brainstorming" sessions with senior engineers, throughout the design process, to bring past experience to bear on new projects.